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DRYING CHARACTERISTICS OF DESICCATED COCONUT AND ITS DRIED PHYSIAL PROPERTIES

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DRYING CHARACTERISTICS

OF DESICCATED COCONUT AND ITS DRIED PHYSIAL PROPERTIES

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ABSTRACT

By conserving agricultural sustainability, the coconut sector greatly contributes to Malaysia's economic and social development. The production of coconut is expected continues to rise in coming years. However, the coconut crop experienced deteriorates after it has been harvested. This study aims to evaluate the drying characteristics of desiccated coconut using convection oven, microwave oven and air fryer. Not only that, the effect of different drying treatment to the physicochemical properties of dried desiccated coconut and the drying behavior of it were study and compare. The coconut flesh was grated to be desiccated form and it were dried through different temperature and power intensities at different time required by using convection oven, microwave oven and air fryer. The temperature of 45°C, 55°C and 65°C were selected to represent different level of the drying temperature and the time required to measure the weight of the dried desiccated coconut at an interval of 30 minutes for the first 4 hours, then every 1 hour for coming 5 hours and lastly weighing the sample at every 5 hours interval until achieve equilibrium weight; the power level of low, medium and heigh which were 100W, 440W and 1000W are selected to launch the experiment and the weight losses of the samples were recorded at an interval of 5 minutes, 3 minutes and 1 minute while the temperature of 120°C, 160°C and 200°C whereby the weight reduction of the sample was recorded at an interval of 3 minutes, 1 minute, and 30 seconds respectively for convection oven drying and air fryer drying. The results obtained through this experiment indicated that the drying time was decreased as the drying temperature or power level increased. Newton model, Page model and Henderson & Pabis model were fitted into the during curve for each drying treatment. In all the drying treatment to dry the desiccated coconut, Page model was determined to be the best model based on its greatest R^2 and lowest RSME values. Based on the results obtained, the lower the temperature and power level that applied to the drying treatment indicated the highest final moisture content of dried desiccated coconut in convection oven drying, microwave oven drying and air fryer drying (1.1758 g water/ g dry solid, 1.1028 g water/ g dry solid, and 1.2465 g water/ g dry solid) respectively. In convection drying treatment at temperature of 55°C produce the largest particle size of 17.55mm while microwave oven with 1000Wpower intensity and air fryer with 160°C produce the largest particle size as 17.68mm and 19.16mm respectively.

Moreover, in densities analysis, convection oven drying, microwave oven drying and air fryer drying at 65°C, 100W and 200°C have the highest value of bulk density, tapped density and true density (0.21±0.0079 g/cm^3, 0.24±0.0049g/cm^3 and1.0209±0.0004 g/cm^3; 0.21±0.0073 g/cm^3, 0.26±0.1533 g/cm^3 and 1.0381±0.0006 g/cm^3; 0.21±0.0230 g/cm^3, 0.24±0.0362 g/cm^3 and 1.0053±0.0007 g/cm^3) . For color evaluation, the data showed that air fryer drying treatment had a darker color in compared to convection oven drying and microwave oven drying. In term of the quantity of surface oil content, convection oven drying at 65°C, microwave oven drying at 1000W and air fryer drying at 200°C has highest yield of surface oil content which are 0.0229±0.0007g, 0.0255±0.0013g and 0.0192±0.0004g respectively. Finally, convection oven has higher power consumption and higher cost of equipment. Thus, the air fryer drying treatment will be more efficient than convection oven drying treatment and microwave oven drying treatment as the equipment is affordable and the power consumption is moderate among convection oven and microwave oven.

ABSTRAK

Dengan memelihara kemampanan pertanian, sektor kelapa banyak menyumbang kepada pembangunan ekonomi dan sosial Malaysia. Pengeluaran kelapa dijangka terus meningkat pada tahun-tahun akan datang. Walau bagaimanapun, tanaman kelapa mengalami masalah kemerosotan selepas dituai.

Kajian ini bertujuan untuk menilai ciri-ciri pengeringan kelapa kering menggunakan ketuhar perolakan, ketuhar gelombang mikro dan penggoreng udara. Bukan itu sahaja, kesan pengeringan yang berbeza terhadap sifat fizikal kelapa kering yang telah dikeringkan dan kelakuan pengeringannya telah dikaji dan dibandingkan.

Isi kelapa telah diparut menjadi isi kelapa yang kering dan ia dikeringkan melalui suhu dan keamatan kuasa yang berbeza pada masa berbeza yang diperlukan dengan menggunakan ketuhar perolakan, ketuhar gelombang mikro dan penggoreng udara.

Suhu 45°C, 55°C dan 65°C telah dipilih untuk mewakili tahap suhu pengeringan yang berbeza dan masa yang diperlukan untuk mengukur berat kelapa kering yang dikeringkan pada 4 jam pertama dengan selang 30 minit, kemudian 5 jam seterusnya dengan selang 1 jam dan akhir sekali menimbang sampel pada setiap selang 5 jam sehingga mencapai berat keseimbangan.

Paras kuasa rendah, sederhana dan tinggi iaitu 100W, 440W dan 1000W dipilih untuk menjalankan eksperimen dan penurunan berat sampel direkodkan pada selang 5 minit, 3 minit dan 1 minit manakala suhu 120°C, 160°C dan 200°C di mana pengurangan berat sampel direkodkan pada selang 3 minit, 1 minit, dan 30 saat masing-masing untuk pengeringan ketuhar perolakan dan pengeringan penggoreng udara.

Keputusan yang diperolehi melalui eksperimen ini menunjukkan bahawa masa pengeringan berkurangan apabila suhu pengeringan atau tahap kuasa meningkat. Model Newton, model Page dan model Henderson & Pabis telah dipasang ke dalam lengkung semasa untuk setiap rawatan pengeringan. Dalam semua rawatan pengeringan untuk mengeringkan kelapa kering, model Page telah ditentukan untuk menjadi model terbaik berdasarkan R^2 terbesar dan nilai RSME terendah.

Berdasarkan keputusan yang diperoleh, semakin rendah suhu dan tahap kuasa yang digunakan untuk rawatan pengeringan menunjukkan kandungan lembapan akhir kelapa kering yang paling tinggi dalam pengeringan ketuhar perolakan, pengeringan ketuhar gelombang mikro dan pengeringan penggoreng udara (1.1758 g air/g pepejal kering, 1.1028 g air/ g pepejal kering, dan 1.2465 g air/ g pepejal kering) masing-masing.

Dalam rawatan pengeringan perolakan pada suhu 55°C menghasilkan saiz zarah terbesar iaitu 17.55mm manakala ketuhar gelombang mikro dengan keamatan kuasa 1000W dan penggoreng udara dengan 160°C menghasilkan saiz zarah terbesar masing -masing iaitu 17.68mm dan 19.16mm.

Selain itu, dalam analisis ketumpatan, pengeringan ketuhar perolakan, pengeringan ketuhar gelombang mikro dan pengeringan penggoreng udara pada 65°C, 100W dan 200°C mempunyai nilai ketumpatan pukal tertinggi, ketumpatan ditoreh dan ketumpatan sebenar (0.21±0.0079 g/cm^3, 0.24±0.0049 g/cm^3 and1.0209±0.0004 g/cm^3; 0.21±0.0073 g/cm^3, 0.26±0.1533 g/cm^3 and 1.0381±0.0006 g/cm^3; 0.21±0.0230 g/cm^3, 0.24±0 .0362g/cm^3 and 1.0053±0.0007 g/cm^3).

Untuk penilaian warna, data menunjukkan bahawa rawatan pengeringan penggoreng udara mempunyai warna yang lebih gelap berbanding dengan pengeringan ketuhar perolakan dan pengeringan ketuhar gelombang mikro.

Dari segi kuantiti kandungan minyak permukaan, pengeringan ketuhar perolakan pada 65°C, pengeringan ketuhar gelombang mikro pada 1000W dan pengeringan penggoreng udara pada 200°C mempunyai hasil kandungan minyak permukaan yang paling tinggi iaitu 0.0229±0.0007g, 0.0255±0.0013g dan 0.0192±0.0004g masing -masing.

Akhir sekali, ketuhar perolakan mempunyai penggunaan kuasa yang dan kos peralatan yang lebih tinggi. Oleh itu, rawatan pengeringan penggoreng udara akan lebih cekap daripada rawatan pengeringan ketuhar perolakan dan rawatan pengeringan ketuhar gelombang mikro kerana peralatannya berpatutan dan penggunaan kuasa adalah sederhana antara ketuhar perolakan dan ketuhar gelombang mikro.

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LIST OF ABBREVIATIONS

%	Percentage
CI	Carr Index
d_{pi}	Sieve size
g	Gram
HR	Hausner Ratio
k	Constant value of the model following an Arrhenius expression
kg	Kilogram
MR	Moisture Ratio
n	Constant of the model
R^2	Coefficient of determination
RSME	Root mean square deviation
t	Time
V_b	Occupied volume of the sample inside the cylinder without any tapping
X	Free moisture content
X^*	Equilibrium moisture content (kg equilibrium moisture kg dry solid^{-1})
x_i	Mass fraction of each sieve size

X_t	Moisture content at time
ρ_B	Bulk density
ρ_T	Tapped density
ρ_V	True density

CHAPTER 1

INTRODUCTION

1.1 Background

Moisture content in agriculture's crops has an effect on its physical, chemical, freshness, and long-term stability. Additionally, it determines the quality of the food products prior to consumption and is processed by the food manufacturer. According to Zeki Berk (2018), the moisture content of the crops and other items must be measured since it affects food safety, storage conditions, and shelf life. Additionally, it affects the taste, texture, weight, and appearance of the meal, with minute changes in moisture content affecting the physical appearance of food. For instance, excessively dry material can decrease the quality of the final product. As stated in (Guiné, 2018) , chemical composition or nutitional value will be affected as Vitamin C or thiamine that can be found in food easily affected by the heat that applied or oxidation since both are relatively sensitive to heat,

Coconut palm which known as *Cocos nucifera L.* was classified in Arecaceae family that is widely farmed in tropical region for its edible fruit, the coconut. It was found practically everywhere along tropical coasts and are believed to have originated in Southeast Asian country. They are the most economically significant palm species, as coconuts constitute a major crop in the tropics and are regarded as the world's most important tree crop, supplying consumption product and constructing material for housing for the people around the world (Child, 1974). Coconut is farmed in nearly 100 countries on an area of almost 12 million hectares. Additionally, half million of the coconut can be produced per year. It is economically significant, culturally significant, and has numerous beneficial uses for people, including providing food, drink, fibre, wood, medicine, energy, and shelter. It is an extraordinary tree that produces over 300 goods (Statista, 2019).

One of Malaysia's first agriculturally based industry is the coconut industry with a throughput of 538,685 metric tonne with a value over RM 600 million at a total planted area around 85,000 hectares(MAZWAN Muhammad, 2020.). However, the coconut sector continues to be one of the classic smallholder crops that serves as the primary source of income for a hundred thousand families. The smallholding sector, which makes up about 90% of the entire land and supports roughly 8000 families, continues to dominate the coconut business. Recently, this sector has demonstrated the potentiality to be improved and further developed in order to meet the rapid growing of consumer needs, especially from downstream coconut-based industries. The government is attempting to recognise the coconut industry's potential as a new source of income because it has the ability to increase the income of the grower (Dardak & Yon, 2021).

One of the most common usages of coconut value-added product is desiccated coconut. It is the coconut flesh that powdered or shred by using a steel shredder or pin mill after a mature and fresh coconuts are shelled and husked off. Thus, it was dried for approximately 10 hours by using a hot air dryer at 80°C to 90°C in order to lower the moisture content to 3% (Swamy, n.d.). The desiccated coconut is easier to transport and has a longer shelf life after it has been dried. It is frequently used in baked goods, puddings, ice creams, and confectioneries. It can be added for texture enhancement, enhanced coconut taste, as a garnish for savoury recipes, as a dusting for the outer layer, and as an alternative to raw shredded coconut.

Desiccated coconut can be utilized in obtaining the virgin coconut oil. (Prasanna & Gunathilake, 2007) reported virgin coconut oil has a thin viscosity, resembles pure water, and is free of particles. It becomes solid at temperatures less than 250 degrees Celsius. It has a mild coconut flavour and aroma, a long shelf life, and a high resistance to oxidation. It is stable at high cooking temperatures, preventing the formation of free radicals due to saturation. VCO is coconut oil extracted directly from the coconut kernel, without any chemical or physical alterations. Coconut oil produced wet or dry is devoid of free fatty acids (less than 0.1 percent) and has a slight coconut flavour.

Drying is a system that incorporates heat and mass transfer to reduce the moisture content from a high to a minimal level (Guiné. ,2018). Additionally, this technique benefits fruit by increasing its shelf life, reducing the product's weight, and thus enabling transportation. Numerous drying technologies, including vacuum, microwave, heat pump, supercritical, freeze, and hot air drying, have been effectively employed in postharvest technology. As a result, it is an energy-intensive process. In a nutshell, drying is oldest existing, most diversified, and most popular process.

The coconut industry contributes significantly to economic development and sociocultural at Malaysia by maintaining the sustainability of agriculture. The production of coconut was subjected to raise in years by the usage of technology in coconut cultivation such as selected hybrid and inbred varieties as well as the effective agronomic practice (MAZWAN Muhammad, n.d.). Since the physicochemical and drying characterises are considered as the quality of raw material that might affect efficiency of the drying process, some specific studies have been done in investigating the drying method on desiccated coconut.

1.2 Problem Statement

Coconut is the fourth agriculture crops in Malaysia after oil palm, rubber and rice. Most coconuts planted in Malaysia are grown on a small scale by small scale farmers as a monoculture crop. In 2016, Malaysia had a total coconut plantation area of 84 609 hectares.

Prior research has addressed drying kinetics and thin layer drying for grated coconut, with most of these experiments utilising either a convective type of dryer or hot air dryer. According to Agarry and Aworanti (2012), the dehydrated process for coconuts exhibited falling rate period properties. Due to the complexity of the interior moisture movement processes in coconuts, the constant rate period was clearly not seen. Nonetheless, previous drying studies made no attempt or supplied data for desiccated coconut dried using an alternate conductive drying method. Grated coconut is dried in uncontaminated condition to with a maximum of 5 percent moisture which apply as the raw material for extracting virgin coconut oil. To obtain pure coconut oil (VCO) by the fresh dry process, dehydrated grated coconut was mechanically pressed for oil extraction (Mansor et al., 2012).

Drying of desiccated coconut is being with the selection of mature coconuts that have been de-husked. To facilitate drying, the fresh kernel is shredded using an electric grater or deshelled, the brown testa is removed, and the coconut shredder is used to smash the coconut (Yahya et al., 2020a). Coconut flesh that has been grated should be dried immediately in an appropriate drier. Thus, the dried desiccated coconut can be preserved for further proceed to extraction process of virgin coconut oil by low-pressured oil extractor.

In this investigation, 3 different drying equipment is used to dry the desiccated coconut to a moisture content of lower than 3% with different drying condition. Longer drying times will result in increased shrinkage and hardness, decreased bulk density, and reduced ability for rehydration, all of which will have an impact on the quality of the dried goods (Pereira et al., 2007). Therefore, the rate at which the desiccated coconuts dried by convection ovens, microwaves, and air fryers is crucial. In addition, the drying rate of the dehydrated coconut is affected by the various temperatures or power intensities utilised in these drying treatments. Depending on the drying procedure, dried desiccated coconut has distinct dried physicochemical characteristics in terms of particle size, density, colour, and surface oil content. The dry physical features of desiccated coconut are crucial because they influence the consumer acceptance and even how the desiccated coconut will be stored and packaged.

References can be made to academic studies on mathematical and experimental drying modelling under varied drying conditions (Manzoor et al., 2019; Niamnuy & Devahastin, 2005; Yahya et al., 2020b). The basic heat and moisture transfer model created by predicted the fluctuation in drying temperature, moisture loss, and surface browning with good agreement (Zhang and Datta, 2006). Realistic boundary conditions must be established for various types of drying equipment and conditions, as well as for the best possible product quality, in order to comprehensively validate the model (Khatir et al., 2012).

1.3 Objectives

1. To evaluate the drying characteristic of desiccated coconut using convection oven, air fryer and microwave oven and air fryer.
2. To study the physicochemical properties of dried desiccated coconut obtained from different drying treatment.
3. To model the drying behaviour of desiccated coconut by using convection oven, microwave oven and air fryer and compare the operating cost for each drying equipment.

1.4 Thesis Layout

This thesis consists of five chapter where the first chapter includes with the introduction, problem statement and the objectives of this present work. Chapter two is reviewing the literature of previous study related to this research project. Chapter three present about the complete experimental procedures to launch the laboratory work in obtaining the drying characteristics and its dried physicochemical properties of desiccated coconut like drying profile, mathematical modelling of drying, final moisture content, the particle size analysis via using sieve shaker, density analysis, color, flowability and surface oil content with a preliminary cost analysis of running each drying equipment under different temperatures and power levels for convection oven, microwave oven and air dryer. The data obtained through the laboratory work will be brought up in chapter four together with the discussion after performing complete experiment, mathematical modelling on the data obtained and simple cost analysis. Hence, Chapter five is covered by conclusion and further recommendation of this present work and come together with appendices part for the overall study research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Coconut

According to DebMandal & Mandal, (2011), coconut was known as the tree of the life and became a worldwide well know food and energy crops particularly in Southeast Asia. The report of stated that several Southeast Asia countries such as Philippines, India, Thailand, and Sri Lanka are the leading coconut cultivator which supplied over 90% total amount of coconut needs all around the world. Over half of the harvested coconut is consumed freshly and another 70 percent of the coconut is used domestically whereby majority of the edible coconut goods are made from the flesh; the white color solid endosperm and the water; the liquid endosperm (Grimwood,1975).

Konan KJL, (1997) stated that a ready-to-harvest mature coconut consists of an average of 16 percent 18 percent and 33 percent for shell, coconut water and both husk and kernel respectively. After removing of the shell and husk, it was named as copra where it is a dried sections of the meat of the coconut palm (Cocos nucifera) that can produced various coconut products.

Copra, a dried mature coconut kernel containing more than 5 percent of moisture was known as the most important coconut goods in producing countries (Roberto et al., 1996). The endosperm begins to grow as a liquid composed of free nuclei and some cells approximately 6–8 months after fertilization. At 11 months, the cells on the endocarp surface continue to form, culminating in transparent jelly-like endosperm and then white solid endosperm or kernel. Under the soft eye, the embryo is about the size of a pea seed (Cutter et al., 1952; Child, 1974).

Among the plantation crops, coconut has the greatest economic significance for Malaysia as a potential source of employment and wealth. Due to its widespread use and the coconut palm's capacity to thrive in a variety of climatic and soil conditions, there is a significant demand for coconuts. The development of new products for raising manufacturer incomes depends critically on the value addition of coconut. Coconut byproducts and products can serve a variety of commercial needs (Swamy, n.d.).

Coconut milk, dried coconut, or copra, desiccated coconut, coconut oil, coconut water, Nate-de-coco, coconut flour, vinegar, jaggery, and other food products from coconuts are among the list. Both a food and an oil seed crop, coconut is. Figure 1 illustrates the various food products with added value that may be made from coconut. These many coconut products have potential of room for growth, value addition, and commercialization.

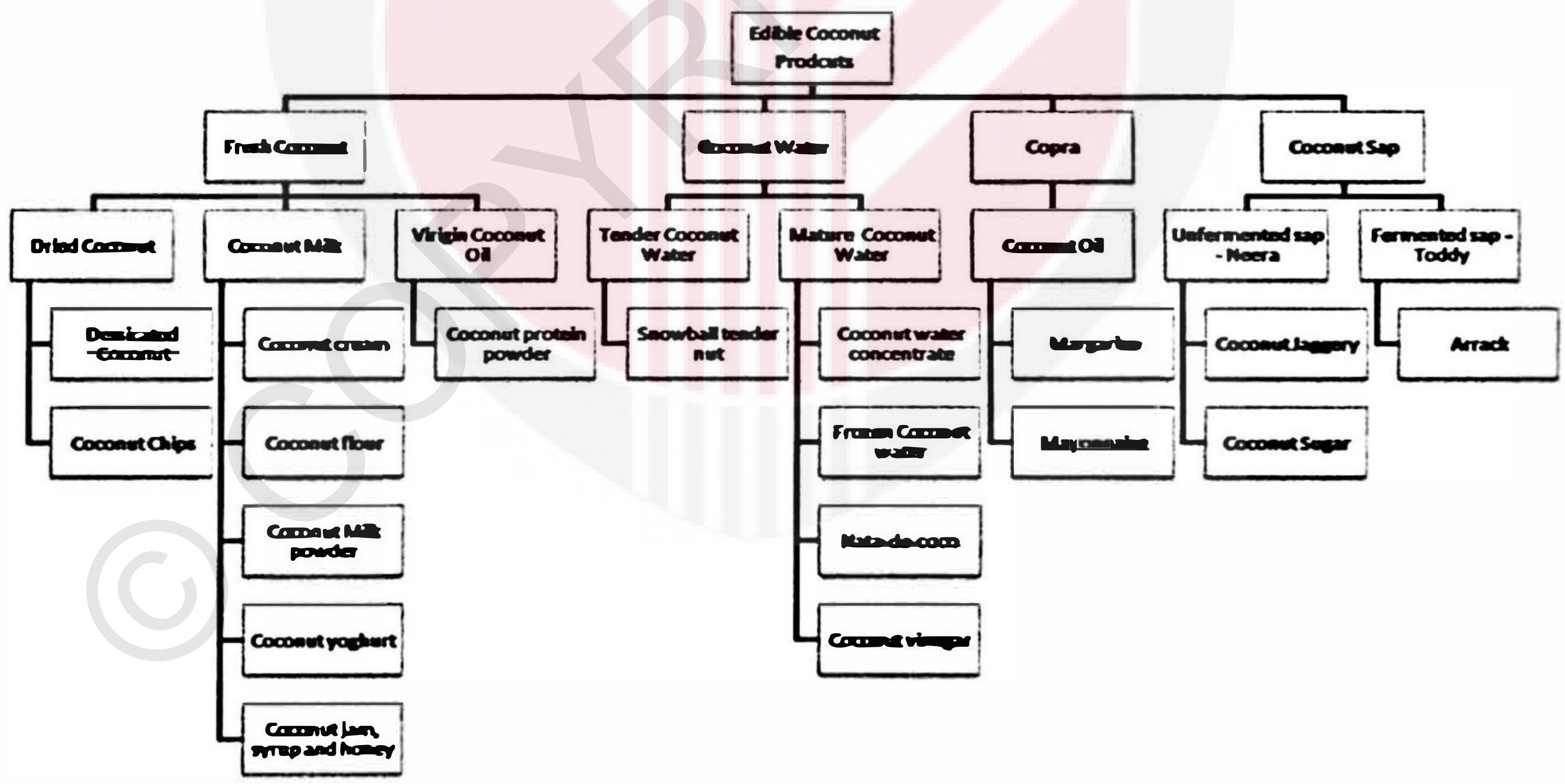

Figure 1: Various food products with added value that may be made from coconut (Swamy, n.d.).

2.2 Overview of Desiccated Coconut

Desiccated coconut is a culinary product made from dried, white, granular, or shredded coconut kernels. Desiccated coconut is made by dehydrating shredded coconut after it is separated from the brown testa and the shredded coconut will go through pre-treatment to eliminate the microbial count for 20 minutes and dried with a hot air dryer at 80°C to 90°C around 10 hours. (Sangamithra et al., 2013). De-husking and shelling mature coconuts are two separate procedures that can be accomplished using market-available machinery. To minimise the microbiological count, grated coconuts or coconut flakes are blanched in steam for approximately 20 minutes. The shredded coconut is next dried in a laboratory convective cabinet dryer unit with varying air temperature (50°C and 60°C) with specific air flow and rotational speed to determine the drying behaviour where the colour, time consumed to fully dried the coconut sample and moisture content reduction will be measured (Yahya et al., 2020a).

Figure 2: Shredded coconut that existed in the market.

Figure 3: Fine coconut that existed in the market.

2.2.1 Nutritional Value of Desiccated Coconut

According to Khuwijitjaru et al., (2012), desiccated coconut has 68.99 percent carbs, 25.59 percent fat, and 0.85 percent protein. Carbohydrates make up most desiccated coconut's components, which include cellulose, hemicellulose, mannose, glucose, manno-oligosaccharides, and insoluble pectin. Most carbs are classified as dietary fibre that has not been digested by endogenous enzymes in the small intestine of humans (Xiong et al., 2017).

2.3 Codex Standard for Desiccated Coconut (Codex Stan 177-1991)

This Standard is applicable to desiccated coconut that complies with its definition. Salted, sugared, flavor-infused, or roasted items are not covered by this Standard. One of the coconut value-added products is grated desiccated coconut (Cocos nucifera L.). De-husking, peeling, grinding, drying, and sifting are the steps in the producing this good. A variety of particle sizes are used when manufacturing the product that been marketed. For commercialization, grated desiccated coconut is divided into three varieties based on the product's approach that can be implemented as follows Table 1.

Table 1: Classification of desiccated coconut according to the standard.

Classification	Description
Extra-fine desiccated coconut	Defined as grated desiccated coconut, with a minimum of 90% of the weight readily passing through a sieve with 0.85 mm square holes and a maximum of 25% of the weight passing through a 0.50 mm aperture size.
Fine desiccated coconut	Defined as desiccated coconut, of which no less than 80% must easily pass through a sieve with a square aperture size of 1.40 mm, but no more than 20% may pass through a sieve with a square aperture size of 0.71 mm.
Medium desiccated coconut	Defined as grated desiccated coconut, of which no less than 90% must easily pass through a sieve with a square aperture size of 2.80 mm, but no more than 20% may pass through a sieve with a square aperture size of 1.40 mm.

An appropriate desiccated coconut on market should be in natural to light creamy white color and have a distinctive texture while the flavor must be particular to the product and free from off flavors caused by deterioration or the absorption of foreign materials. Moreover, the aroma must be distinctive to the product and must not be rancid, moldy, cheesy, smokey, fermented, or have any other unfavorable odors. Yet, the chemical and physical properties can be referred to Table 2.

Table 2: Chemical and physical properties of a desiccated coconut (Codex Stan 177-1991).

Parameters	Requirements
Moisture	Less than or equal to 4%
Oil content	More than or equal to 60% m/m for desiccated coconut processed through processes including de-husking, hatching, paring, washing, comminuting, drying, and filtering.
Foreign matter	Shall be free from any apparent or visible matter or material.

2.4 Drying Method

Drying has always been critical for prolong the life span and consequently, the primary reason for drying food is to reduce their moisture content inside the food products. Only the deployment of adequate drying methods will result in an improvement in product quality and a reduction in post-harvest losses. Drying is thought to be the most traditional and important way of preserving agricultural products, being used for centuries. It dehumidifies and preserves items. The moisture removal process is a combination of heat and mass transfer. Drying, or the elimination of moisture, inhibits the growing and generation of microbes that cause spoilage to the products; it also limits the deteriorative processes caused by moisture. Additionally, it can result in significant weight and volume reductions, lowering packing, storage, and shipping costs, and enabling the product to be stored at room temperature. Several changes occur during drying, inclusive of the physico-chemical and structural moderation that can influence the final quality of the products (Inyang et al., 2017).

2.4.1 Convection Oven

The convection oven drying principle is based on the phenomenon of convection, in which the heating element produces energy that is dissipated by convection, resulting in a nearly uniform temperature throughout the oven. It is accompanied by rapid heat, mass, and momentum transfer, as well as energy transfer by convection from the hot air to the exterior part of product. Normally, the sample structure would influence the convection or diffusion of the transferred process into the interior of the sample. Additionally, the heat flux causes the temperature of the product to rise, which lead the moisture in it to evaporate as it is removed from the sample's interior via diffusion, convection, or capillarity and thus transforms into vapour as it is removed from the sample's surface to the surrounding air via convection. It is crucial to highlight that convection drying has its own limitations because it used to be operated at high temperatures during the falling rate period and requires lengthy drying times. This eventually results in a thermally deteriorated and developed an unexpected product (Inyang et al., 2017).

A variety of research have been conducted utilising this technology to dry agricultural goods. This equipment was used by Altaf et al., (2015) to extract and characterise pectin derived from papaya (Carica papaya Linn.) peel. Nonetheless, disadvantages came along by using convection drying as it will be operated at high temperatures during falling rate period or longer drying time which may lead the product to thermally degradation and become undesirable (Demiray et al., 2017).

2.4.2 Microwave Oven

Microwave drying has been utilised in the food sector as an alternative method. It dehydrates food through the interaction between electromagnetic radiation and the polar molecules contained inside the material, which cause the polar molecules to rotate in response to the oscillating electromagnetic wave applied. The orientation of these molecules occurs frequently and fast in a high frequency electric field resulting in the molecular friction and the generation of heat. The most used electromagnetic waves are between 0.3 GHz and 300 GHz.

Microwave heating is a desirable alternative drying method since it increases energy efficien cy and has a negligible effect on the quality of dehydrated items (Huang, 2013; McGurk et al, 2017). It has grown popular because it prevents the product's quality from deteriorating and enables the speedy and efficient distribution of the heat in between the material. Additionally, it minimises the time for dehydrating the product and energy consumption during the drying process while producing a high quality and satisfied dehydrated food products (Balbay et al., 2011; Li et al., 2010; Dong et al, 2011; Silva et al.,2007).

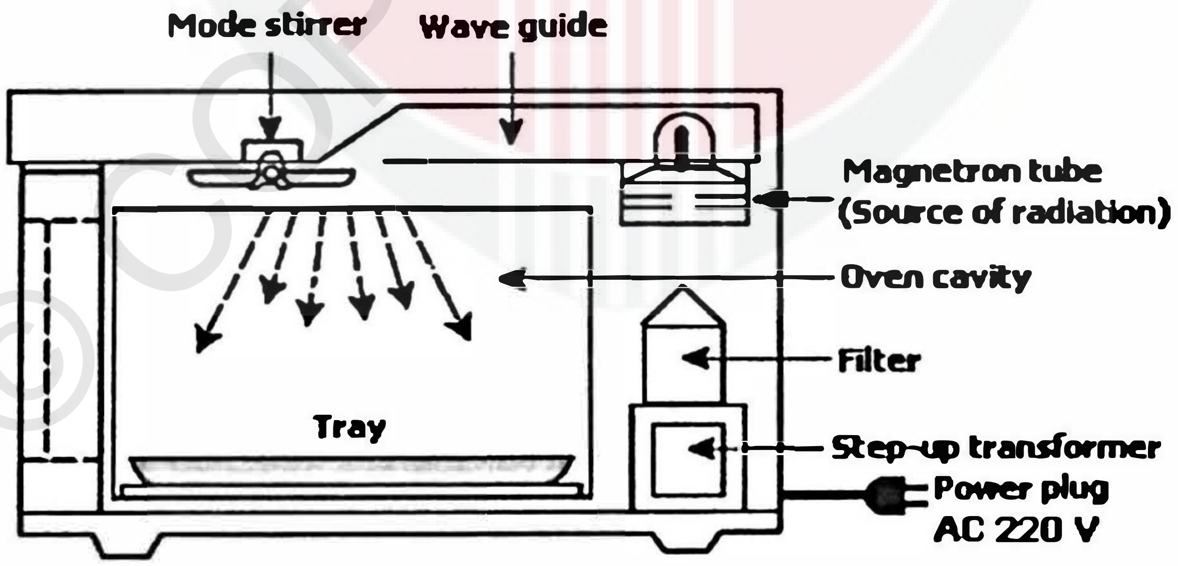

Figure 4: A schematic diagram of a Microwave Oven (Lule, F., & Koyuncu, T. 2017).

The several disadvantages of convection drying can be readily avoided by using a microwave oven. They not only aid to reduce drying time, but they also help to reduce case hardening, conserve taste and color, and offer an overall desirable finished product. However, (Feng et al., 2012) reported one of the microwave oven's shortcomings is the non-uniform heating inside the cavity. There has been no previous research on drying coconut in a microwave oven. But some research work by using microwave oven did exist to dry other agricultural goods such as banana peel (Anuar et al., 2019a) with 3 different level of power (100W, 440W and 1000W) and resulted lowest final moisture content and lowest bulk density with drying treatment under 1000W. In this study, total of three different drying equipment such as convection oven, microwave oven and air fryer were used to dry the desiccated coconut thus continued investigated to compare and understand the drying kinetics of each.

2.4.3 Air Fryer

Anon (2019) stated that air fryer was introduce by Philips Electronics Company in the year 2010 as a new cooking technology. Yet, the air fryer is a relatively new development in the commercialization of the drying method on food products. The use of an air dryer results in homogeneous, hygienic, and visually appealing items that may be manufactured quickly. The air fryer operates on the same concept as hot air drying in that a particular amount of moisture is removed from the sample to reduce water activity until it reaches a level that inhibits microbe activity and prevents enzymatic and non-enzymatic reaction from occurring. It is critical to understand the drying process, including the requirement for hot air drying and the effect of processing variables such as hot air velocity, air temperature, and sample size on drying behaviour (Inyang et al., 2017).

Unfortunately, it seems to be no research into the effects of utilising air fryers for drying on product quality. This is backed up by Arafat (2014), who found no references or scholarly papers that detail the mechanics and dynamics of mass transfer occurrences and volume changes that occur during hot air frying. After years, (Mior Zakuan Azmi et al., 2019) did a research on air fryer and convection oven at 150°C, 160°C and 170 °C with vary baking time and found that an optimum temperature of 25°C with a bake time of 25 minutes produce a relatively high in firmness and moisture content for a cake. As a result, the effects of employing an air fryer on the drying of desiccated coconut have been investigated in this experiment.

2.5 Drying Characteristics

2.5.1 Drying Profile

In this investigation, drying time was defined as the amount of time between the samples' initial and final moisture contents. The quantity of moisture evaporated out from sample per unit of time was referred as the drying rate. It was found that how temperature affected the amount of time it took for agricultural products to dehydrated sufficiently, such as red pepper, apple and leek slices (Nasiroglu and Kocabiyik, 2007). It is crucial for the drying treatment and applied to determine the moisture level of samples at any drying time to model the drying kinetics of food samples. During the process, drying curves are represented as a function of time and dimensionless moisture ratio,(MR) (Gamli, 2014) .

2.5.2 Mathematical Modelling for Drying

The study of drying kinetics and behaviour is essential and can be done effectively with mathematical modelling. According to Menges & Ertekin, (2006), mathematical equations are fundamental for estimating drying times and generalising drying curves. This is significant in terms of food safety, sensory quality, and nutritional value (Castro et al., 2018). Many studies were conducted on the drying behaviour of agricultural goods such as banana peels (Khawas et al., 2014), lemon slices (Torki-Harchegani et al., 2016), and dika nuts and kernels have been undertaken in recent years (Agregbesola et al., 2015).

According to Ertekin and First (2015), the derivation of Newton's law of cooling and also the Fick's second law of diffusion were applied to obtain the mathematical model for drying. In order to choose the best drying conditions, which are crucial for the equipment design, optimization, and enhancing the quality of the dried food, it is vital to model and describe the drying data. Considering this, mathematical modelling, including thin-layer modelling, can be a crucial tool for summarising experimental data as well as for optimising the drying process and, ultimately, for lowering the overall energy consumption (Buzrul, 2022). Even though there are theoretical, semi-theoretical (semi-empirical), and empirical thin-layer models, the empirical equations are still extensively employed due to their simplicity and ease of computation (Sopade et al., 2007). Since theoretical models are based on the general theory of heat and mass transport laws and reflect the principles of the drying process, their parameters have physical significance. after gone through some thin-layer drying modelling, three mathematical modelling as Newton Model, Page Model and Henderson & Pabis Model were selected since it were catogorized as semi-empeirical method which function in the rage of model developing when the study works with a few factors as stated, air velocity, temperature, relative humidity and moisture. However, time requirement and the shape of the sample that used to be dried out the water content need not to be considered in these models (Parry, J.L., 1985). The selected models in this study can also be used to explain the processes that take place during drying (Buzrul, 2022).

2.5.2.1 Newton's Model

Drying rate is directly proportional to the difference between the present moisture to equilibrium moisture content was stated in Newton's law of cooling which is used to derived and obtaining the newton's model for the use of mathematical modelling in drying. Equilibrium of the moisture was obtained when the weight loss of the sample has zero changes at certain drying condition. This model is relying on the product's exterior resistance, ignoring any resistance to moisture movement within the material (Lewis,1921). Previous work has done by determine the best fit mathematical modelling for plantain samples drying by an oven dryer with a temperature range from 40°C to 70°C until the weight is equilibrium. However, Newton Model was failed to be the best fit as it has highest constant k value but lower R^2 value and larger X^2 values compare to Page Model (Oduola, 2016). The equation below represented by the equation stated below (Eq.(1)).

$$MR = \exp(-kt) \tag{1}$$

Whereby:

k = Constant value of the model following an Arrhenius expression

t = Time

2.5.2.2 Page Model

The page model is an advanced version of Newton's model because it incorporates a nondimensional constant n into the terms, which influences moderating the time and provides more accurate predictions for moisture loss (Avhad & Marchetti, 2016). According to (Akoy, 2014) a research work had done to study the experimental characterization and modelling of thin layer drying of mango slices where Page model was the best fit model to represent the drying characteristics with highest R^2, and lower SSE, χ^2 and RMSE values. So example of findings were stated for sweet cherry, raw mango slices and potato slices (Doymaz and Ibrahim (2011); Goyal *et al.* (2006) and Aghbashlo *et al.* (2009))

$$MR = \exp\left(-kt^{n}\right) \tag{2}$$

whereby

k = Constant of the model according to an Arrhenius expression

n = Constant of the model

t = Time

2.5.2.3 Henderson & Pabis

Fick's second law of diffusion were applied for derivation to obtain the Henderson and Pabis model and known as a bi-parametric exponential model (Iguaz et al., 2003). (Özdemir & Onur Devres, 1999) reported that Henderson & Pabis model was use to evaluate according to MSE, R^2, and the mean relative deviation (P) modulus. However, it resulted R^2 value highest than acceptable range. When the drying process only takes place during the falling rate phase and the liquid diffusion control process, coefficient K is correlated to the effective moisture diffusivity (Avhad et al., 2016).

$$MR = a\exp\left(-kt\right) \tag{3}$$

whereby

a = Material shape which usually known as a dimensionless constant

k = Effective diffusivity when the drying phase involved is the falling rate period was assumes / Moisture movement in material through liquid diffusion

t = Time

2.5.3 Moisture Content

Amjad, Crichton, Munir, Hensel, & Sturm, (2017) revealed that the amount of moisture in the foodstuff will have an impact on the rate of shrinkage and color change. Therefore, accurate assessment of the moisture content is crucial to creating a relationship between the product's quality characteristics and moisture content during the drying process in order to optimize the drying process. Moisture content and water activity had a significant impact on the specific heat and thermal diffusivity (Özdemir & Onur Devres, 1999). Moreover, temperature and moisture content both had a linear effect on the density of Brazilian orange juice, with the water content in the orange juice having a greater impact than temperature was stated by (Telis-Romero et al., 1998).

2.6 Physicochemical Characteristics

2.6.1 Sieving Method

Sieve analysis recognize as the traditional and well-known method to obtain the particle size through mass or volume. According to (Devine, Samsam, & Daniell, 2007) stated the characterizing of a sample's particle size distribution by using a mesh screen, sieve tray, net, or the separating of wanted elements from unwanted material known as the purpose of sieving. Generally, a sieve can be used to divide and break up the clumps from various dry material such as flour or any kind of powder as well as to mix up them. In sieve analysis, the particle material will be divided into various size fractions thus the determination on the weight of these fractions meaning that in this analysis, the broad particle size spectrum can be analyzed efficiently.

2.6.2 Density Analysis

Fitzptrick et al., (2004) reported the powder flow characteristics are crucial because they influence on powder behaves during handling, processing, and storage. When making direct compression tablets, a particle size distribution with a large range could result in particle segregation and flow disruptions. If the powder qualities are not sufficiently studied, flow issues may cause danger incident while handling the powder.

Leuenberger, (1982) revealed the capacity of a powder to shrink in volume when subjected to pressure is known as compressibility. Yet, the porosity of the powder is affected by the particle size and shape, and more porous powder allows for increases in compressibility. Ong et al, (2014) reported that particle size distribution is significant since great differences in particle size make it difficult to compact the powder because the smaller particles fill up the spaces in between the larger ones, making it less porous. Thus, a smaller particle size distribution would cause a sample to become more denser in densit (Fielding et al., 2012).

Table 3: The specification of Carr Index and Hausner Ratio according to Lebrun et al.,2012.

Carr Index (%)	Flow Character	Hausner Ratio
1-10	Excellent	1.00-1.11
11-15	Good	1.12-1.18
16-20	Fair	1.19-1.25
21-25	Passable	1.26-1.34
26-31	Poor	1.35-1.45
32-37	Very poor	1.46-1.59
>38	Very, very poor	>1.60

Table 4: Carr classification of flowability according to the Angle of Repose from Carr RL,1965.

Description	Angle of Repose
Very free flowing	25°-30°
Free flowing	30°-38°
Fair to passable flow	38°-45°
Cohesive	45°-55°
Very cohesive	>55°

2.6.3 Colour

Pereira et al., (2007) reported a Colour Spectrophotometer was appointed to determine the colour measurement via indicating the CIE chromaticity coordinates where the lightness (L*), redness (a*), and yellowness (b*) scales show the indication of the degree of discolouration happened and a review from the study stated that the result indicated the foodstuff quality in term of the colour was slightly affected by the processing condition such as the power used in drying process. Previous work on drying treatments affected the colour on guava slices was done by (Ali et al., 2016). The data obtained shown that the longer the drying time or existing of oxygen indicated the guava slice became darker. However, increasing of b* in this case indicated the guava slice become more yellowish compared to fresh guava slice. Similar research of colour on rose petals, pumpkin and green pepper had been done as reported in (Akoy, 2014; KAUR et al., 2008; Selvi et al., 2020)

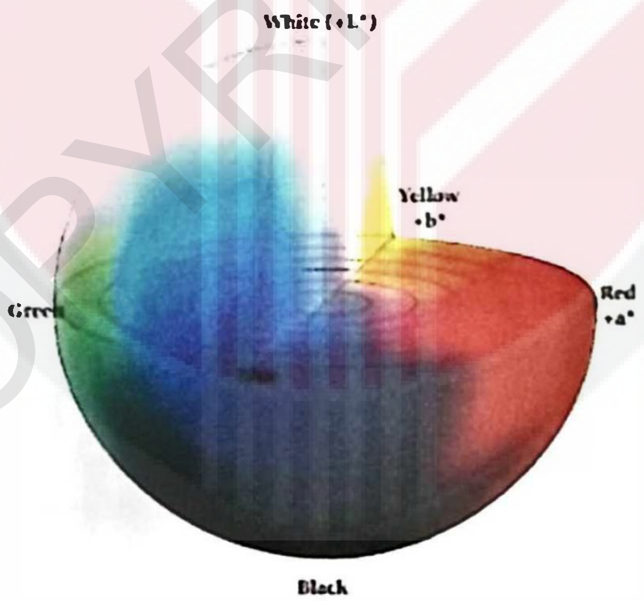

Figure 5: CIE L*a*b*color space (Konica-Minolta, 2015).

2.6.4 Surface Oil Content

According to (Niamnuy & Devahastin, 2005), there has not been any recent experimental work on the usage of coconut or items derived from coconut were conducted to get deeper investigation of its properties. To examine the effects of different drying variables on the drying kinetics and some quality features of the dried products, batch fluidized bed drying experiments of coconut were conducted in this publication. Additionally, some studies were conducted to contrast the drying rates and product quality of the dried goods produced under constant and time-dependent drying settings as in different inlet air velocity and stepwise change of inlet air temperature by (Devahastin & Majumdar,1999; Chua, Mujumdar, Hawlader, Chou, & Ho, 2001).

However, Codex Standard for Desiccated Coconut stated that the desiccated coconut that existed in the market was categorized in 3 groups which are desiccated coconut that made without oil extraction in accordance from basically white kernel obtained from the coconut whole nut that has reached the proper development for processing, desiccated coconut that processed properly going through processes including de-husking, hatcheting, paring, washing, comminuting, drying, and filtering and desiccated coconut that whereby oil has partially been extracted using suitable physical methods in compliance. The oil content of these 3 different groups of desiccated coconut product should obey the requirement as below:

Parameter	Desiccated Coconut Product	Requirements
Oil content	• Desiccated coconut that made without oil extraction in accordance with basically white kernel obtained from the coconut whole nut that has reached the proper development for processing • desiccated coconut that processed properly going through processes including de-husking, hatcheting, paring, washing, comminuting, drying and filtering	⩾ 60% m/m
	• Desiccated coconut that whereby oil has partially been extracted using suitable physical methods in compliance	⩾ 35 < 60% m/m

2.7 Preliminary Cost Analysis

Industrialization contributed to attempts to remain competitive in worldwide. It emphasis the level of expenditures for a firm to make and generate revenue, which is all businesses primary objective. When compared to its peers, a company may be less effective at producing sales if it has substantially greater operating expenses as a percentage of profits. Analysis of operational performance to every firm must include with operating expenses. Therefore, it is crucial for both internally and externally analysts to discover a company's operating expenses, comprehend its main cost factors, and evaluate management effectiveness (CFI Team, 2022) . Operating costs are the ongoing expenses incurred from the normal day-to-day of running a business that include both costs of goods and other operating expenses which often called selling, general, and administrative expenses. A simple cost analysis had been done to convection oven drying method (Mohammad S. N. H., 2018). However, in related study still lack of recent preliminary operating cost analyses research work that had been done to the microwave and air fryer which can be considered as existed technology and latest technologies in food industry. Hence, a simple cost analysis is performed to compare the operating cost in concern of the price of drying equipment and drying time to the power consumption and industrial tariff rate for convection oven drying, microwave oven drying and air fryer drying that applied in this project work in order to dry desiccated coconut with different temperatures and power levels.

CHAPTER 3 METHODOLOGY

3.1 Introduction

Raw material which uses to complete the study were purchase from a local supermarket that located near Sri Serdang, Selangor. In obtaining the samples, the white solid endosperm from de-husked coconut were shredded to fine granular. Thus, the sample was kept in deep freezer model DW-40L508 for further usage. Figure 1 shows the de-husked coconut while Figure 2 shows the shredded coconut flesh which is the sample used in completing the experiment.

Figure 6: De-husked coconut.

Figure 7: Shredded coconut flesh.

There are three different drying experimental equipment used to conduct the experiments to investigate the drying and physicochemical properties of desiccated coconut. Thus, the initial weight of drying tray was recorded for every set of samples. Hence, the drying temperature, drying time and the final weight of the sample were measured to determine the moisture content.

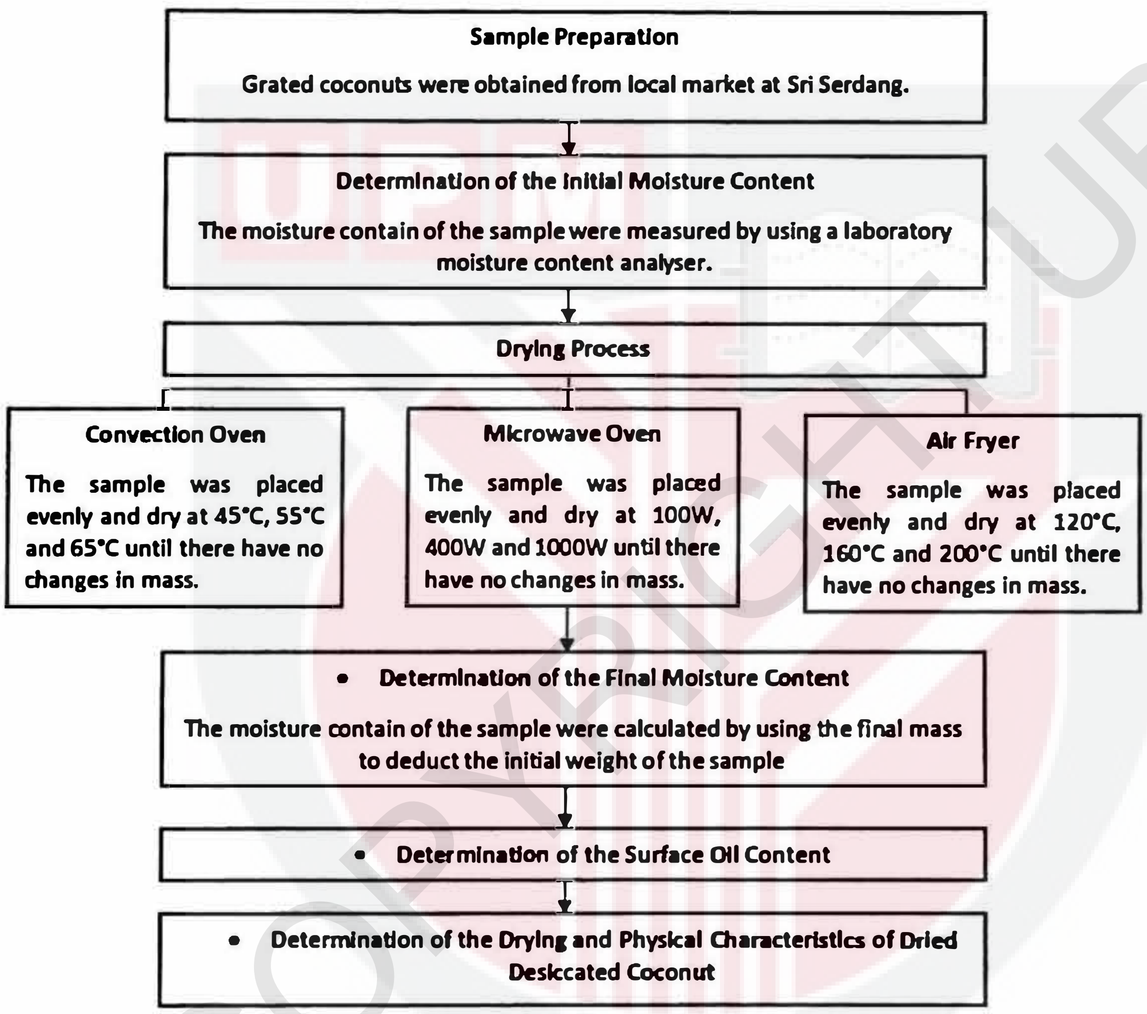

Figure 8: Flow chart of the Project Work.

3.1.1 Material Preparation

The frozen shredded coconut was taken out from the freezer and placed in room temperature for further usage. After de-frost of it, the shredded coconut was weighed by an analytical balance (AY220, Shimadzu, Japan) for 20g each. Hence, the samples were distributed evenly on a small drying tray with a size of 15cm x 10cm x 3.5cm.

3.2 Convection Oven Drying

Figure 9: Convection oven (Memmert, Schwabach, Germany).

Prepared sample was place uniformly on a drying tray and insert into a preheated oven (Memmert, Schwabach, Germany) at low, medium, and high temperature levels. An optimum setting of 45°C, 55°C and 65°C were selected to represent different level of the drying temperature due to the concern of no degradation will occur to the sample as it is a highly fat content food products and not causing browning too quicky during drying treatment. Hence, the weight of the samples was measured at an interval of 30 minutes for the first 4 hours, then every 1 hour for coming 5 hours and lastly weighing the sample at every 5 hours interval until achieve equilibrium weight. The measurement of the experiment was repeated three times for average value. (Sama, 2019).

3.3 Microwave Oven Drying

Figure 10: Microwave oven Panasonic NN-C2003S.

There are 3 different power level used in this investigation. A thin layer of shredded coconut was placed evenly on the drying tray into the microwave oven model NN-C2003S (Panasonic, Malaysia). Hence, the power level of low, medium and heigh which were 100W, 440W and 1000W are selected to launch the experiment and the weight losses of the samples were recorded at an interval of 5 minutes, 3 minutes and 1 minute respectively until no changes in moisture content through getting a constant weight of the samples by using an analytical balance (AY220, Shimadzu, Japan). Following steps is repeated for three times to determine the average value. (Anuar, Tahir, Najeeb and Ahmad, 2018).

3.4 Air Fryer Drying

Figure 11: Hot air fryer (Philips NL9206AD-4 Drachten).

The shredded coconut samples were evenly distributed on a drying tray before it has been placed in a commercialized hot air fryer (Philips NL9206AD-4 Drachten). Various level of temperature was considered which are low, medium, and high at 120°C, 1 60°C and 200°C . The weight reduction of the sample was recorded at an interval of 3 minutes, 1 minute, and 30 seconds respectively. The combination of drying temperature and drying time were recorded while the sample was in weight equilibrium. Following steps is repeated for three times to determine the average value. (Murzaini, Taip, Aziz and Rahman, 2022). To be noted that, temperature from 80°C to 100°C did not show a significant different regarding to moisture content, drying time and the colour to the sample. The sample which was dried under this temperature led to some changes in the smell and colour. Little black dot occurred to the sample that may cause by mould. These changes happened even though the weight of the sample achieved equilibrium during drying. High in final moisture content might be the reason of these changes happening. So, the decision was made to the selection of 120°C, 1 60°C and 200°C for this drying treatment.

3.5 Drying Characteristics

Drying properties of the sample after removal of moisture was investigated through the determination of drying profile and thin layer drying model by mathematical modelling.

3.5.1 Drying Profile

The drying curve and drying rate curve were plotted against the free moisture content, X, and generating the drying profile employed in this investigation. The water loss from dry solids at a specific time was defined as free moisture content, X (%).

$$X = X_t - X^* \quad (4)$$

whereby

X_t = Moisture content at time (t) in drying time (%)

X^* = Equilibrium moisture content (kg equilibrium moisture kg dry solid^{-1})

However, the moisture content at time (t) in drying time was calculated by the formula as below:

$$X_t = \frac{W - W_s}{W_s} \quad (5)$$

whereby

W = Weight of the wet solid (kg)

W_s = Weight of dry solid (kg)

3.5.2 Mathematical Modelling

Mathematical models as listed in Table 3 are fitted to obtained curve fitting indicators such as correlation coefficient (R^2) and root mean square of error, (RMSE) that are used to represent drying time and final moisture levels that provide with expression that have the highest accuracy of the model for drying process are used to calculate the moisture ratio of food items as a function of drying time. The food to be dried affects how empirical models for drying kinetics of food stuff are fitted. The model that is best for the drying kinetics of food samples cannot easily determined with absolute certainty by model fitting. For several food products, investigations focused on drying kinetic studies and appropriate mathematical models are included in Table 4.

Table 5: List of Thin-Layer Drying Modelling with references.

Model No.	Name	Equation	References
1	Page	MR=exp(-k.tn)	Madamba *et al.*, (1996)
2	Henderson & Pabis	MR=a.exp(-k.t)	Henderson, (1974)
3	Newton (Lewis)	MR=exp(-k.t)	Demir *et al.*, (2004)
4	Logaritmic	MR=a.exp(-k.t)+b	Togrul and Pehlivan, (2002)
5	Midilli	MR=a.exp(-k.tn)+b.t	Midilli *et al.*, (2002)
6	Wang and Singh	MR=1+a.t+b.t2	Wang and Singh, (1978)
7	Polynomial	MR=a+b.t+c.t2+d.t3	Gamli, (2011)
8	Logistic	MR=b/[(1+a.exp(k.t))]	Soysal *et al.*, (2006)
9	Weibull	MR=exp(x(t/b)α)	Corzo *et al.*, (2010); Vega-Galvez *et al.*, (2010)

10	Fick's second law of diffusion	MR=8/π2.exp(-(π2Def.t)/4L2)	Ramaswamy and Nsonzi, (1998)
11	Two-factor	MR=a.exp(-k1.t)+b.exp(-k2.t)	Gamli, (2011)
12	Modified page	MR=exp(-(k.t)n)	White *et al.*, (1981)
13	Modified Henderson & Pabis	MR=n1.exp(-k1.t)+n2.exp(-k2.t)+ n3.exp(-k3.t)	Puente-Diaz *et al.*, (2013)
14	Approximation of diffusion	MR=a.exp(-k1.t)+(1-a).exp(-k2.a.t)	Yaldiz *et al.*, (2001)
15	Verma	MR=a.exp(-k1.t)+(1-a)exp(-k2t)	Verma *et al.*, (1985)
16	Thompson	t=a.Ln(MR)+b.[Ln(MR)]2	Thompson *et al.*, (1968)
17	Geometric	MR=a.t-n	Chandra and Singh, (1995)

Table 6: List of mathematical models that commonly used to fit with drying kinetics of some food stuffs in the research.

Mathematical model	**Food stuffs that used to be dried**	**References**
Page and logarithmic	Bamboo slices, rosehip	Kumar *et al.*, (2013); Jena and Das, (2007)
Page, Henderson & Pabis, Weibull, two-term	Olive waste cake	Vega-Galvez *et al.*, (2010)
Newton	Pumkin slice, purslane	Nawirska *et al.*, (2009); Akpinar and Bicer, (2007)
Polynomial	Tomato slice	Gamli, (2011)

Mididlli-Kucuk	Silverside fish, murta berries, carrot pomace, apple tissue, opuntia ficus fruit	Puente-Diaz *et al.,* (2013); Wiktor *et al.,* (2013); Kumar *et al.,* (2013); Toujani *et al.,* (2013)
Henderson & Pabis	Pine forest residue, giant pumkin	Phanphanich and Mani, (2009)
Two-term	Green wheat	Al-Mahasneh *et al.,* (2013)
Page	Tomato, pepper	Doymaz, (2007); Gaware *et al.,* (2010)
Two-term, Page, Modified Henderson & Pabis	Olive leaves	Erbay and Icier, (2007)
Thompson	Pomegranate seeds	Sharma *et al.,* (2011)

Table 7: Mathematical models that chosen and applied to the value of moisture ratio.

Model No.	**Name**	**Equation**	**References**
1	Newton	$MR = \exp(-kt)$	Motevali et al. (2010)
2	Page	$MR = \exp(-kt^n)$	
3	Henderson & Pabis	$MR = a \cdot \exp(-kt)$	Chhinnan (1984)

To determine which thin layer drying model best captured the characteristics of desiccated coconut, three models were investigated. Since the values of M_e are relatively low in comparison to Mt and Mo, the moisture ratio in these models was simplified to M/M_o rather than $(M - M_e) / (M_o - M_e)$ (Akgun and Doymaz, 2005).

According to Ertekin and Yaldiz, (2004), the correlation coefficient (R^2) and root mean square error (RMSE) between the experimental and projected moisture ratio values were the statistical variables utilized to choose the best model. However, if R^2 value is high and RMSE value obtained will be low represent a most suitable model to it. These variables were determined using the following formula:

$$R^2 = \frac{\sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2} \quad (6)$$

$$RMSE = \left(\frac{\sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2}{N}\right)^{\frac{1}{2}} \quad (7)$$

whereby

MR_{exp} = Experimental dimensionless moisture ratio

MR_{pre} = Predicted dimensionless moisture ratio

N = number of experimental data points

Drying curves can be described mathematically using a variety of models, including exponential, semi-exponential, logarithmic, and more. Thin-layer equations used in the mathematical models may help to identify the best drying curves or generally the moisture properties of foods at any stage of drying. By specifying drying equipment or reducing drying time, kinetic models enable companies to select the best drying conditions for the finished product specifications (Vega-Galvez *et al.,* 2010). Taking consideration to the agriculture goods in previous researched that had been done before as spinach leaves, apple slices, and rambutan seeds (Ozkan et al., 2005; Zerein et al., 2013 ;Ahmad et al., 2018) and others as these investigations paves the direction for constructing various drying models. Three different thin-layer modelling as Newton model, Page model and Henderson &

Pabis model had been chosen as these were the most common used specializing in agricultural based stuff drying experiment which can describe the best drying kinetics and drying behavior of desiccated coconut in this research.

3.5.3 Determination of Final Moisture Content

20g of shredded coconut was place evenly on a petri dish and insert to the drying equipment with desire drying condition until it reached equilibrium of the weight. After the sample removed from the drying equipment, it will be kept in desiccator. The reading of final weight of the sample is again measure by analytical balance (AY220, Shimadzu, Japan). Hence, the initial weight of the sample and the final weight of the sample were used to calculate the value of moisture content by using the formula as below. The measurement of moisture content was done triplicates for each condition. Thus, the average value of the data obtained was recorded.

$$X = \frac{W - W_s}{W_s} \qquad (8)$$

whereby

X = Moisture content (%)

W = Initial weight (kg)

W_s = Final weight (kg)

3.6 Dried Physicochemical Characteristics

3.6.1 Mean Particle Size

After finishing the drying process to the sample, the dried desiccated coconut was sieved by using a mechanical test standard laboratory steel sieve shaker (Sieve Shakker Retsch-AS200) with different mesh size that allowing the particles to pass through different size of sieves with and shaken for at least five minutes to obtain the average mean particle size of the dried desiccated coconut sample by using different sieve size varying from 4mm, 2mm, 1mm, 500μm, and 250μm. The mean particle size is determined by using the following formula:

$$\text{Sieve mean diameter} = \frac{1}{\sum \frac{x_i}{d_{pi}}} \quad (9)$$

whereby

x_i = Mass fraction of each sieve size

d_{pi} = Sieve size

3.6.2 Density Analysis

3.6.2.1 Bulk Density

A 50 ml capacity tarred graduated measuring glass cylinder was prepared while 20 g of desiccated coconut was weight by analytical balance (AY220, Shimadzu, Japan). Hence, the sample was poured slowly into the measuring glass cylinder. After completely pour the sample, the occupied volume is without doing any tapping to the sample was observed and data was recorded. Hence, the weight of powder and occupied volume of the sample were used to calculate the bulk density by using the formula as below (Tze et al., 2012). The measurement of bulk density was done in triplicates. Thus, the average data obtained was recorded.

$$\rho_b = \frac{W}{V_b} \tag{10}$$

whereby

ρ_b = Bulk density

W = Weight of the sample

V_b = Occupied volume of the sample inside the cylinder without any tapping

3.6.2.2 Tapped Density

Tapped density is measured straight away after the value of bulk density is taken. The same setting of sample in the measuring glass cylinder was tapped for 120 times on a soft and flat surface with a maximum vertical height of 15 cm to ensure the sample inside the measuring glass cylinder experienced even consolidation from manual tapping motion. Hence, the weight of the sample and occupied volume after the sample subjected to tapping were used to calculate the value of tapped density by using the formula as below (Tze et al., 2012).Thus, the mean value of the result was measured, and it must be repeating for three times.

$$\rho = \frac{W}{V_t} \tag{11}$$

whereby

ρ_t = Bulk density (g/cm^3)

W = Weight of the sample

V_t = Occupied volume of the sample inside the cylinder without any tapping

3.6.2.3 True Density

A Gas pycnometer (AccoPyc II 1340; Pycnometer Micromimetics, U.S.A.) is used to obtain the true density of desiccated coconut where the blank bed Dry Flo needed to be calibrated for 5 cycles. Thus, 4g of sample is then placed inside the bed and the analyser was set to run for 5 cycles. When the system is done for running 5 cycles, the value of true density will be displayed on the analyser and hence, it is recorded.

3.6.2.4 Flowabilities

Angle of repose, Hausner Ratio and Carr index were used to determine the flowability of the sample (Carr. 1965).

3.6.2.5 Hausner's Ratio

According to Hayes, (1987), Hausner's Ratio was used to determine the flowabilities of the sample, cohesion, the compressibility of it and to obtain the friction between the particles. . Hence, the bulk density and tapped density were used to calculate the value of the ratio by using the formula as below. The value of Hausner's Ratio was calculated and done in triplicates. Thus, the average data obtained was recorded.

$$\text{Hausner's Ratio} = \frac{\rho_t}{\rho_b} \qquad (12)$$

whereby

ρ_t = Tapped density

ρ_b = Bulk density

3.6.2.6 Carr's Index

According to (Khot et al., 2017), the tendency of compressible to the powder and the flowabilities of the powder can be measured by Carr's Index where the value of tapped density and bulk density will be taken to obtain the value of it by using the formula as below. The measurement of Carr's Index was done in triplicates. Thus, the average data obtained was recorded.

$$Carr's\ Index = \frac{\rho t - \rho b}{\rho t} \times 100 \tag{13}$$

Table 8: The specification of Carr Index and Hausner Ratio according to Lebrun et al.,2012.

Carr Index (%)	Flow Character	Hausner Ratio
1-10	Excellent	1.00-1.11
11-15	Good	1.12-1.18
16-20	Fair	1.19-1.25
21-25	Passable	1.26-1.34
26-31	Poor	1.35-1.45
32-37	Very poor	1.46-1.59
>38	Very, very poor	>1.60

Table 9: Carr classification of flowability according to the Angle of Repose from Carr RL,1965.

Description	Angle of Repose
Very free flowing	25°-30°
Free flowing	30°-38°
Fair to passable flow	38°-45°
Cohesive	45°-55°
Very cohesive	>55°

3.6.3 Colour

A Colour Spectrophotometer model UltraScan PRO (HUnterLab, United State) was appointed to measure the colour of the desiccated coconut samples from convection oven drying, microwave oven drying and air fryer oven drying after completing the drying process. The colour differences can be calculated from the analysis of desiccated coconut samples by using the colour analysis equipment where the lightness (L^*), redness (a^*), and yellowness (b^*) scales were used to determine the colour changes of desiccated coconut samples. Hence, a comparison against colour standard is required, ΔL^*, Δa^*, and Δb^*, and ΔE are measured by the equation below.

$$\Delta E = \sqrt{(L*)^2 + (\Delta a*)^2 + (\Delta b*)^2} \quad (14)$$

3.6.4 Surface Oil Content

The surface oil content from the samples for every drying method were determined by using a blotting paper where the initial weight of the blotting paper was weight by using analytical balance (AY220, Shimadzu, Japan), thus 5g of sample was placed evenly as a thin layer on the blotting paper and then it was kept in a desiccator for 12 hours. The final weight of the blotting paper was weight by using the same analytical balance.

3.7 Preliminary Cost Analysis for Varying Drying Treatment

The preliminary cost analysis in this study is done by calculating the operating cost with take in consideration to the equipment price. The operating cost for each varying drying treatment is crucial for a startup industrial business as it helps to accomplish the investment for greatest potential return by depending on the cost and equipment resources expenses (Thomas et al., 1969). The simple cost analysis was calculated as below:

$$\text{Operating Cost} = \text{Operating hour (h)} \times \text{Power consumption (kW/h)} \times \text{Tariff rate} \qquad (15)$$

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the findings from the experiment and a discussion on the desiccated coconut drying properties in a convection oven drying characteristics, microwave oven drying characteristics, and air fryer drying characteristics. Section 4.1 discusses on drying characteristics and Section 4.2 discusses on the dried physicochemical characteristics of desiccated coconut.

4.1 Drying Characteristics

4.1.1 Drying Profile

Figures in this section shown the drying curve for desiccated coconut under convection oven drying, microwave oven drying and air fryer drying. The moisture content of the samples under different drying equipment and temperature or power as convection oven (45°C, 55°C and 65°C), microwave oven with the power of 100W, 440W and 1000W and air fryer at temperature of 120°C, 160°C and 200°C with the time required to dry the moisture content of desiccated coconut in order to achieve equilibrium weigh to measure the moisture content in between both weighing intervals for convection oven were 30 minutes for the first 4 hours, then every 1 hour for coming 5 hours and lastly weighing the sample at every 5 hours interval until no weight loss; microwave oven were at an interval of 5 minutes, 3 minutes and 1 minute; air fryer were at an interval of 3 minutes, 1 minute, and 30 seconds respectively was shown in Figure 12, Figure 13 and Figure 14. Dehydration of agricultural goods is crucial as it limit the microbial growth and avoiding the enzymatic degradation process in it (Roshanak, et al., 2016).

According to these three figures, the time required for drying process is impacted by the temperature or power intensities. The drying curve was obtained after taking the average moisture ratio from triplicate the experiment with same amount of sample and same temperature and drying time for each drying condition. The lowest the temperature or power intensities as at 45°C, 100W and 120°C required the longest drying time which were 450 minutes, 15 minutes and 6 minutes respectively. A significant different on the moisture ratio was determined during the drying treatment using air fryer at 200°C due to not appropriate temperature that had been applied led to burnt of the sample. So, the drying treatment was forced to stop before the color of the sample become fully blackened or carbonized state and having a strong tangy taste and aroma. As expected, lower temperatures or power intensity resulted in a slower drying process since the moisture was eventually evaporated slowly proved by (Anuar et al., 2019) . The outcome showed that increased temperature or power intensities in convection oven drying, microwave oven drying or air fryer drying accelerated the mass transfer within the sample. The mass transfer in the drying process of desiccated coconut is the amount of moisture content that evaporated according to the drying time and temperature that applied during the drying process. Yet, in a typical drying treatment, more heat was produced with higher temperature or power intensities generated a significant change in vapor pressure between the surface and center of the product (Bai-Ngew et al., 2010).

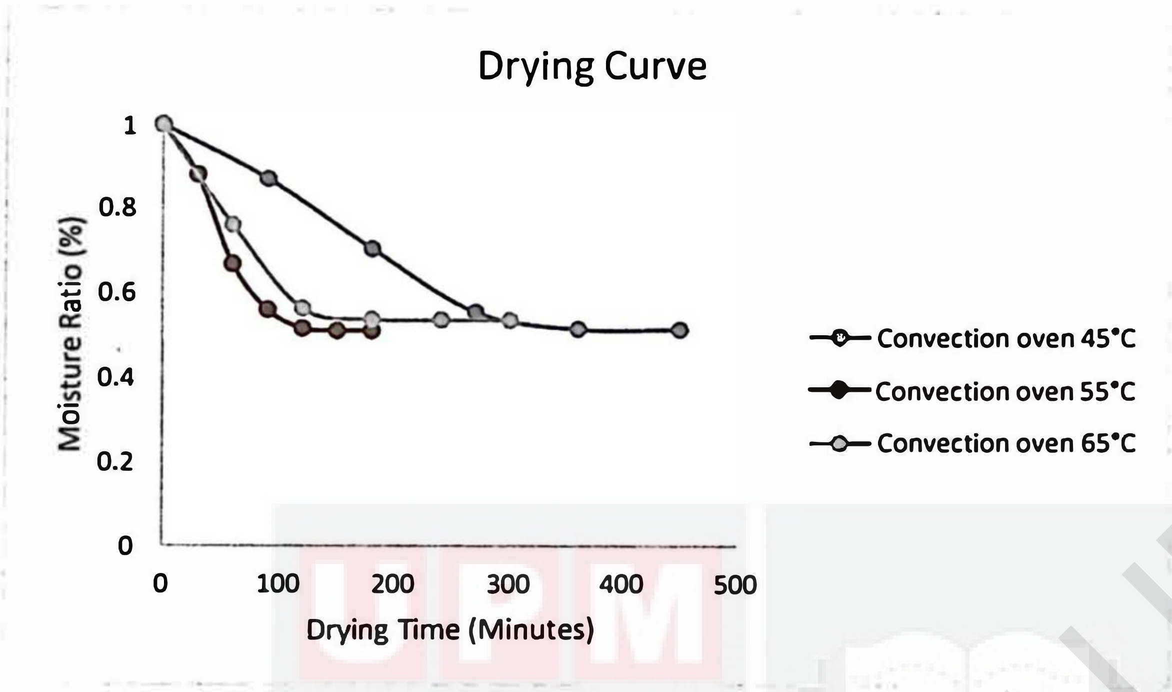

Figure 12: Drying curve for dried desiccated coconut at varying temperature (45°C, 55°C and 65°C) by using convection oven drying.

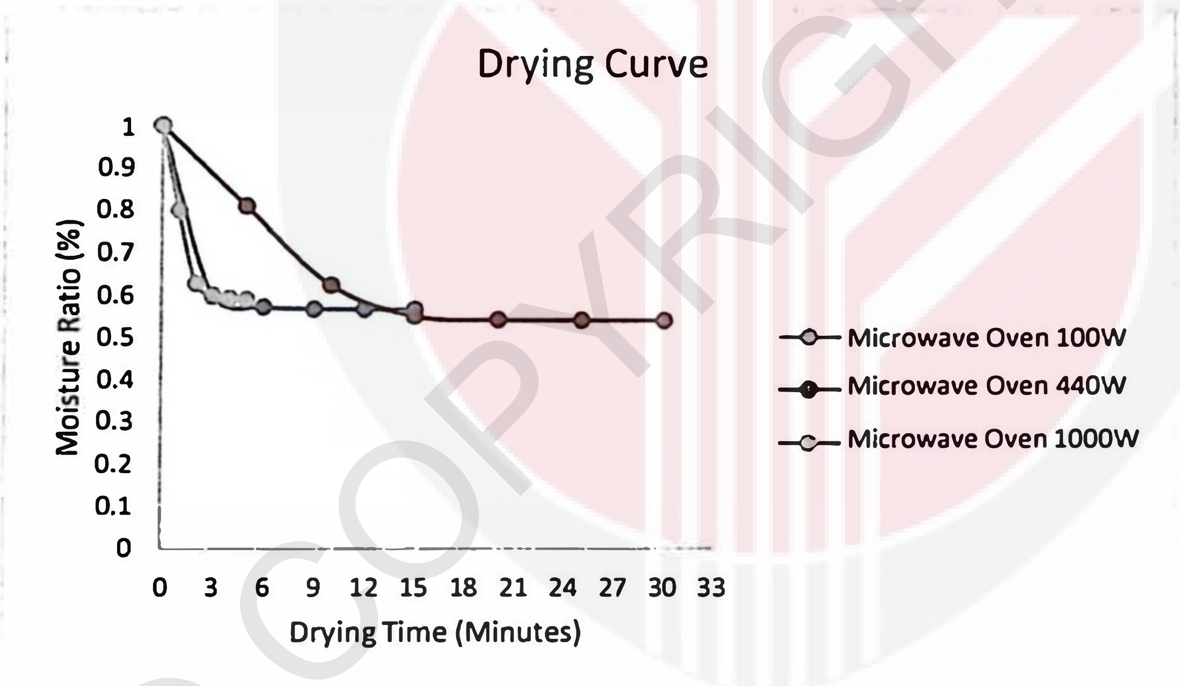

Figure 13: Drying curve for dried desiccated coconut at varying power levels (100W, 440W, 1000W) by using microwave oven drying.

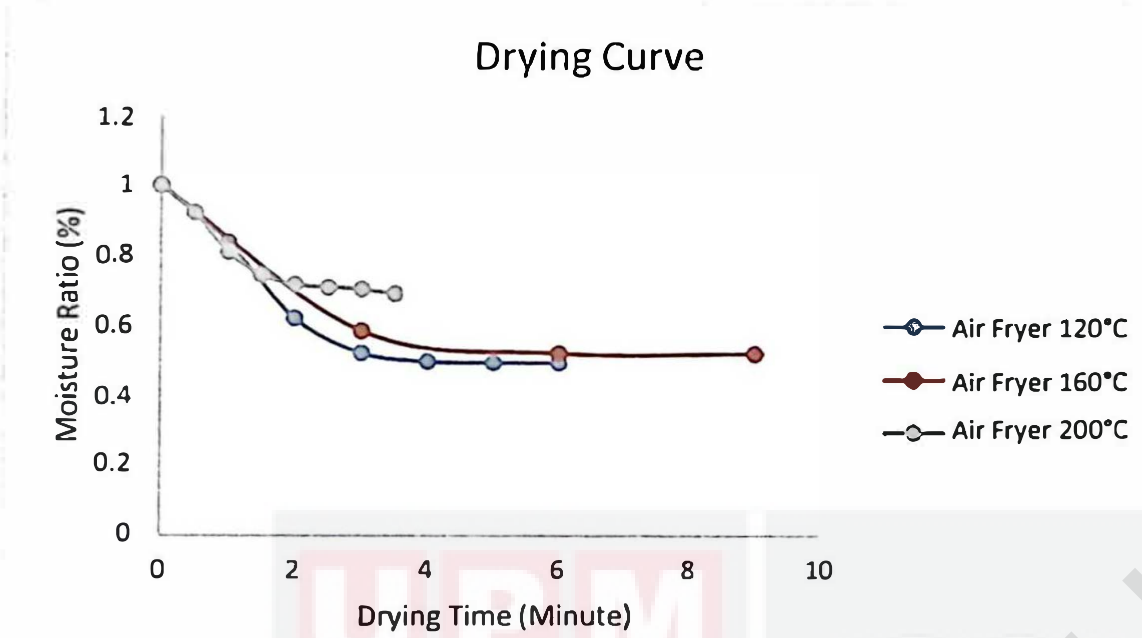

Figure14: Drying curve for dried desiccated coconut at varying temperature (120°C, 160°C and 200°C) by using air fryer drying.

4.1.2 Mathematical Modelling

The results of the statistical analysis are provided in the table below. Three models were used to fit the moisture ratio of dried desiccated coconut. As a result, when drying in convection ovens, microwave ovens, and air fryers, the drying rate, k, increased as the temperature or power intensity increased as shown in Newton, Page and Henderson & Pabis models. Evidence is gathered for spinach leaves, apple slices, and rambutan seeds (Ozkan et al., 2005 ; Zerein et al., 2013 ;Ahmad et al., 2018). The drying rate constant, k value increased from 0.001783894 min^{-1}, 0.003748051 min^{-1}, and 0.001755882 min^{-1} to 0.0049412 min^{-1}, 0.058672273 min^{-1}, and 0.005 $min^{-1}$for convection oven drying ; 0.03301718 min^{-1}, 0.13477292 min^{-1}, and 0.0242152 min^{-1} to 0.1451877 min^{-1}, 0.1451877 min^{-1} and 0.1202579 min^{-1} for microwave oven drying ; 0.100343 min^{-1}, 0.1958369 min^{-1} and 0.08686

min^{-1} to 0.162087835 min^{-1}, 0.5008 min^{-1} and 0.144747034 min^{-1} for air fryer drying in Newton, Page and Henderson & Pabis models respectively.

Most of the cases in this experiment, R^2 values were consistently higher than 0.90 indicating a good fit whereas if R^2 value was high and the RMSE value was low, the model was considered to be good (Madamba et al., 1996; Ertekin and Yaldiz, 2004). In all the drying treatment for desiccated coconut, Page model was determined to be the best model based on its greatest R^2 and lowest RSME values. According to the Table 10, Table 11 and Table 12, the value of R^2 and RSME were in the range from 0.9318 to 0.9885 and 0.014838 to 0.315877059 for convection oven drying; 0.8247 to 5202 and 0.013706 to 0.053405 for microwave oven drying and from 0.663 to 0.9931 and 0.00556 to 0.0325 for air fryer drying, respectively. The microwave drying of spinach leaves, the microwave vacuum drying of durian chips, and the microwave drying of rambutan seed all exhibited similar outcomes (Ozkan et al., 2005; Bai-Ngew et al., 2010; Ahmad et al., 2018). Thus, the thin layer drying behavior of dried desiccated coconut can be believed to be approximated by the Page model.

Table 10: The value of different parameters which representative the models at different temperature in convection oven drying.

Temperature (°C)	Models	Constant Parameter			R^2	RMSE
		k (min^{-1})	n	a		
45	**Newton**	0.001783894			0.9866	0.016053
	Page*	0.003748051	0.870237943		0.9704	0.014838
	Henderson & Pabis	0.001755882		0.992280321	0.987	0.015976
55	**Newton**	0.004			0.9708	0.048618
	Page*	0.01931224	0.713961925		0.9318	0.020378832
	Henderson & Pabis	0.002466249		0.91707586	0.9885	0.031178
65	**Newton**	0.0049412			0.9839	0.026283218
	Page*	0.058672273	0.43428253		0.8059	0.016345
	Henderson & Pabis	0.005		1.03	0.9836	0.315877059

*** symbol indicated the best fitted model for every drying treatment at different temperatures.**

Table 11: The value of different parameters which representative the models at different microwave power levels.

Power (W)	Models	Constant Parameter			R^2	RMSE
		k (min^{-1})	n	a		
100	Newton	0.03301718			0.9802	0.03849907
	Page*	0.13477292	0.48478604		0.8336	0.01752464
	Henderson & Pabis	0.0242152		0.9165546	0.9892	0.03116556
440	Newton	0.05781342			0.9844	0.053405
	Page*	0.58263677	0.1		0.5202	0.032167
	Henderson & Pabis	0.03841502		0.84254693	0.993	0.043333
1000	Newton	0.1451877			0.989	0.030607
	Page*	0.28570441	0.44442104		0.8247	0.013706
	Henderson & Pabis	0.1202579		0.92602579	0.9924	0.026678

*** symbol indicated the best fitted model for every drying treatment at different power level.**

Table 12: The value of different parameters which representative the models at different temperature in air fryer drying.

Temperature (°C)	Models	Constant Parameter			R^2	RMSE
		k (min^{-1})	n	a		
120	**Newton**	0.100343			0.9825	0.0325
	Page*	0.1958369	0.6269557		0.9292	0.0106441
	Henderson & Pabis	0.08686		0.92794	0.9868	0.0299
160	**Newton**	0.147842773			0.9931	0.031587531
	Page*	0.272770493	0.612579942		0.8903	0.020494012
	Henderson & Pabis	0.1300772		0.9656051	0.9946	0.0156745
200	**Newton**	0.162087835			0.9809	0.0174758
	Page*	0.5008	0.1		0.663	0.00556
	Henderson & Pabis	0.144747034		0.942597581	0.9847	0.029288131

*** symbol indicated the best fitted model for every drying treatment at different temperatures.**

4.1.3 Final Moisture Content

Figure 15 illustrated the final moisture content for different drying treatment and temperature or power. From the values of final moisture content obtained for this section proved that the final moisture content achieved the moisture content range that stated in Chemical and physical properties of a desiccated coconut (Codex Stan 177-1991) which is equal or less that 4% of final moisture content. In convection oven drying treatment, the final moisture content of desiccated coconut was 1.1758, 1.1304 and 1.0987 g water/ g dry solid for temperature of 45°C, 55°C and 65°C respectively which prove that the final moisture content was decreased while the temperature was increased. The higher the temperature contribute to greater amount of water evaporation and increased the collision in between the molecules resulting lower amount of final moisture content. However, Ureta et al., (2016) discovered that the use of natural convection, which is without air flow during drying, in the convection oven led to lower effective temperatures. In this experiment, the maximum temperature setting did not result in the lowest final moisture content since the highest temperature requires the lowest drying time which cause the water molecules in the sample did not obtain sufficient energy to evaporate as the temperature rises, the rate of evaporation increases. This makes sense since more molecules move rapidly at higher temperatures, increasing the probability that a molecule will have enough energy to separate from a liquid and turn into a gas.

For microwave oven drying, the time of drying reduced accordingly to the level of power. The value of final moisture content for power level at 100W, 440W and 1000W were 1.1028, 1.0506 and 0.9905 g water/ g dry solid. With the increases of microwave power level, the temperature obtained in the drying chamber, or the intensity of microwave supply also increased resulting the moisture to evaporate more rapidly and shortened the drying time (Minaei et al., 2012).

According to the graph of final moisture content below, the measurement of final moisture content via air fryer at the temperature of 120°C, 160°C and 200°C proposed a similar trend of shorter drying time with higher drying temperature as the convection oven drying and microwave oven drying. The final moisture content of temperature at 120°C, 160°C and 200°C were 1.2465, 1.2250 and 0.9420 g water/ g dry solid. This drying method gives the lowest final moisture content among varying drying treatment. It can be justified that the average heating rate in the air fryer was faster than convection oven and microwave oven. The amplitude of oscillation was larger due to smaller cooking chamber for air fryer compared to convection oven and microwave oven that required shorter drying time for drying. These results demonstrated that operating the oven under conditions of rapid airflow boosted the drying temperature's efficiency. Additionally, oscillation amplitude increased when drying with the air fryer.

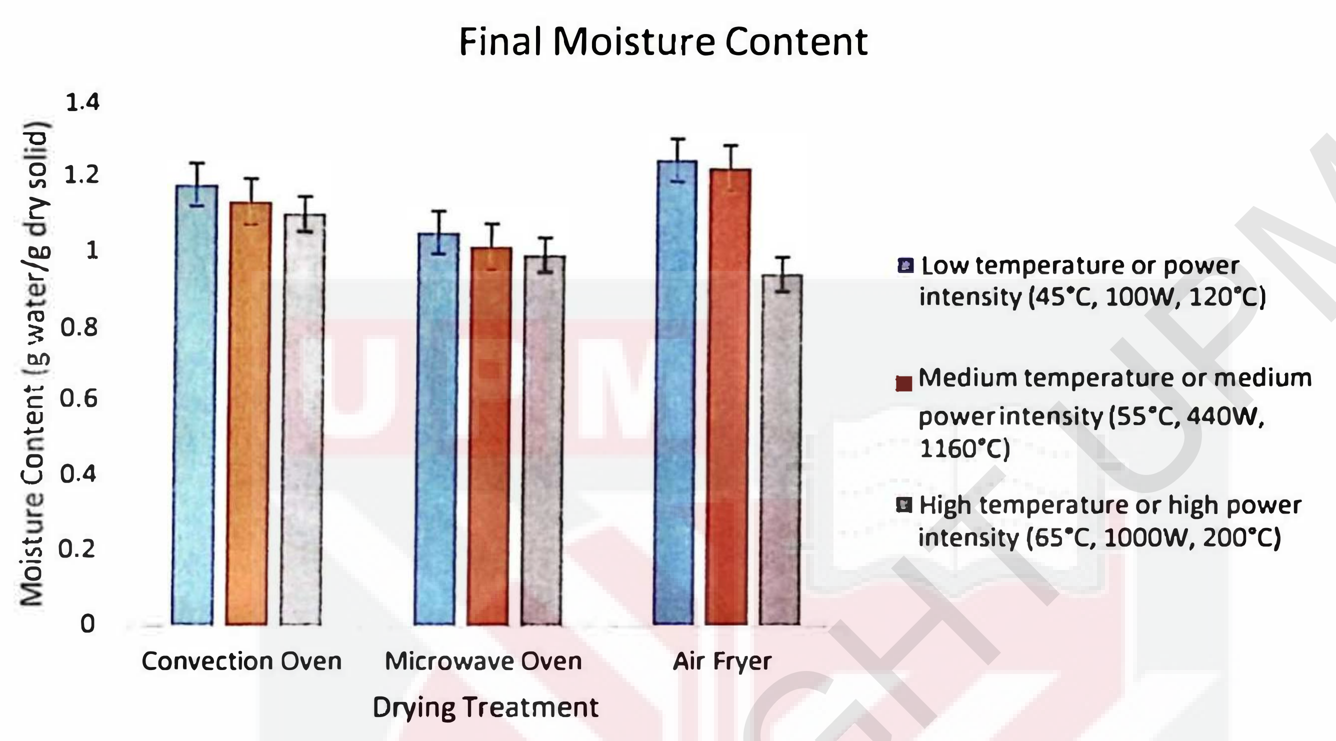

Figure 15: Final moisture content of dried desiccated coconut from different drying treatment.

4.2 Dried Physicochemical Characteristics

4.2.1 Particle Size Analysis Using Sieve Shaker

The detailed particle size that stated according (Codex Stan 177-1991) can be referred to Table 1 in Section 2.3 which were classified to three categories as extra fine desiccated coconut, fine desiccated coconut, and medium desiccated coconut. For convection oven drying, microwave oven drying and air fryer drying gave value of particle size distribution in between the rage of 4mm to 250μm by using sieve shaker. For convection oven drying, the average mean particle size at 45°C, 55°C and 65°C were 17.08mm, 17.55mm and 17.52mm. however, for microwave oven drying at 100W, 440W and 1000W, the average mean particle size of dried desiccated coconut were 16.69mm, 16.76mm and 17.68mm whereas air fryer drying at 120°C, 160°C and 200°C were 17.50mm, 19.16mm and 18.03mm respectively. In microwave oven drying showed the trend of increasing in average mean particle size when the drying power intensity increased which is significant different from convection oven drying and air fryer drying where the average particle size at medium temperature increased (17.52mm and 19.16mm) hence decreased (17.52mm and 18.03mm) at high temperature. KeShun Liu, (2009) stated the abrasive level, moisture content, duration of sieving and percussion during sieving of dried particle or the attrition occurs during the sieving procedure leads to a size reduction of particles and might cause errors in particle size estimation.

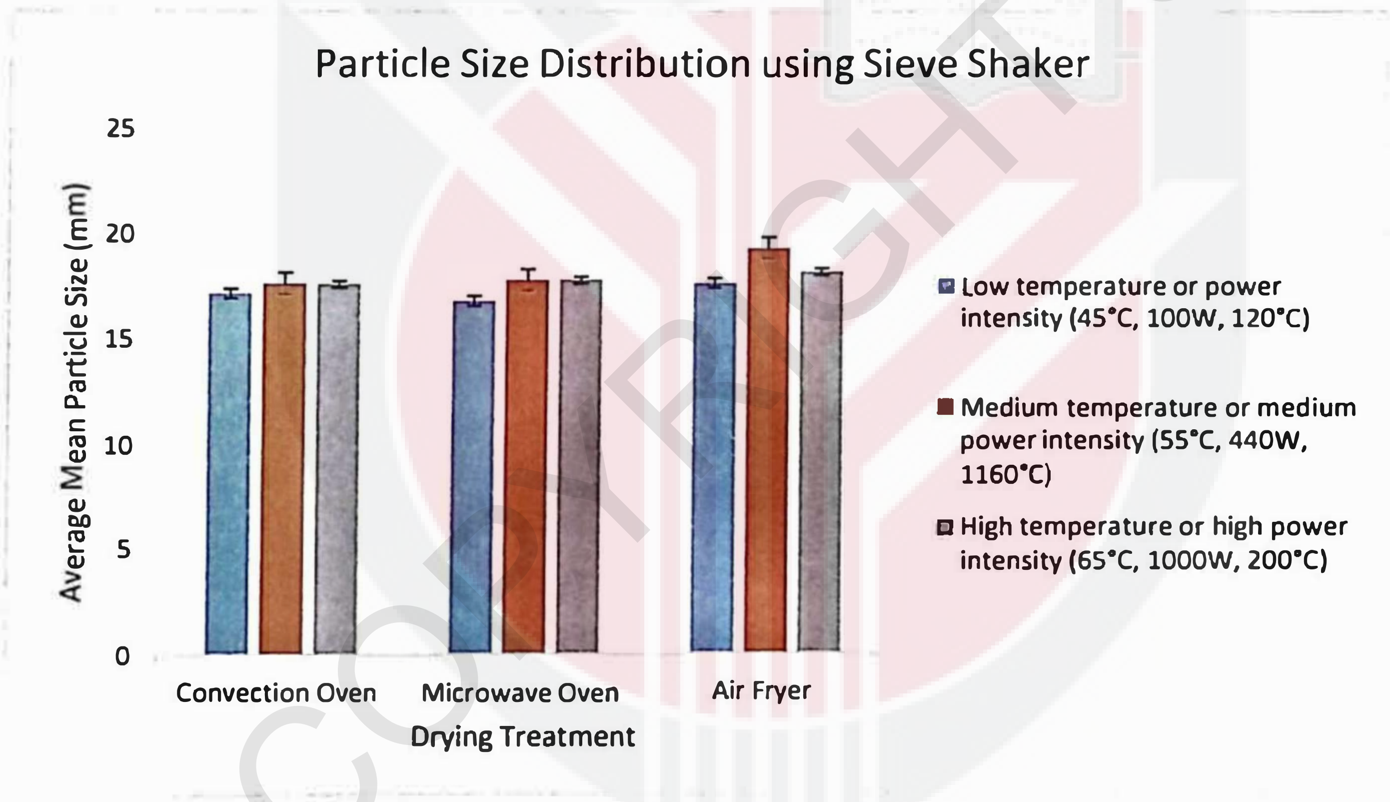

Figure 16: Particle size distribution by using sieve shaker.

4.2.2 Density Analysis

The effectiveness of the powder is significantly influenced by its density. The bulk and tapped densities provide information about the packaging and arrangement of the particles as well as the compaction profile of a material chosen to address this issue. Bulk density, or the degree of packing that may be attained when external forces are applied, is one of a powder key characteristics which reflects the volume of a mass of sample after enforcing a denser packing of the particles (Mirhosseini & Ahmid, 2013).

From the results obtained in Table 13, the bulk density and tapped density of dried desiccated coconut under convection oven drying treatment (45°C, 55°C and 65°C) ranged from 0.20±0.0409 g/cm^3 to 0.21±0.0079 g/cm^3 and 0.23±0.0542 g/cm^3 and 0.24±0.0062 g/cm^3 while the sample under microwave oven drying treatment (100W, 440W and 1000W) were 0.20±0.0167 g/cm^3 to 0.21±0.0127 g/cm^3 and 0.24±0.0121 g/cm^3 to 0.26±0.1533 g/cm^3 thus the sample under air fryer drying treatment (120°C, 160°C and 200°C) were ranged from 0.18±0.0126 g/cm^3 and 0.21±±0.0230 g/cm^3 and 0.22±0.0136 g/cm^3 and 0.24±0.0362 g/cm^3. It can be observed that convection oven drying treatment and air fryer drying treatment exhibited higher bulk and tapped density as the temperature of drying increased. This scenario was reported by (Roongruangsri & Bronlund, 2015) and (Seifu et al., 2018) on pumpkin powders and onion powders.

However, in microwave oven drying, the result obtained for both bulk density and tapped density are ranged from 0.20±0.0167 g/cm^3 to 0.21±0.0127 g/cm^3 and 0.24±0.0121 g/cm^3 and 0.26±0.1533 g/cm^3 which were in contrary with the finding by (Manzoor et al., 2019) where microwave oven drying should present the trend of higher power resulted in lower bulk and tapped densities whilst lower powers that applied in drying of the sample effected the sample to become denser. More moisture evaporated due to higher power, which decreased the density of sample. Error may occur due to improper drying procedure, or the sample was undergone degradation by oxidation. The transport of moisture to the surface is more dynamic in microwave heating than in convective drying because the material being heated is being heated internally rather than only on the surface.

Nonetheless, Choi & Okos support the view that temperature has little to no impact on the density of dry solid where linear temperature dependent correlations for the solid densities of pure components have been shown, but the temperature dependency is negligible. The temperature dependence is discovered to be rather significant for convection oven drying treatment where the value obtained were 1.0155±0. 0008 g/cm^3, 1.0121±0.0004 g/cm^3 and 1.0209±0.0004 g/cm^3 at 45°C, 55°C and 65°C. Even when the experimental data is satisfactorily described, extrapolating the results to temperatures outside the range of experimental data could result in considerable deviations. For microwave oven drying method with the powers of 100W, 440W and 1000W presented the value of true density at 1.0381±0.0006 g/cm^3, 1.0218±0.0008 g/cm^3 and 1.0268±0.0014 g/cm^3 while air fryer drying treatment at 120°C, 160°C and 200°C proposed the value of true density as 1.0292±0.0012 g/cm^3, 1.0042±0.0003 g/cm^3 and 1.0053±0.0007 g/cm^3 respectively. The data about the compressibility of dried desiccated coconut under varying drying treatment verified the statement from Johanson, (1978) where the combined influences of moisture content, particle size, and interparticle cohesive force determine the densities of powders, every difference in a particular attribute may result in a significant change in the bulk, tapped, and actual densities of powders.

Table 13: The value of tapped density, bulk density, and true density for desiccated coconut under varying drying treatment.

Drying Treatment	Temperature (°C) / Power (W)	Mass (g)	Bulk density (g/cm^3)	Tapped density (g/cm^3)	True density (g/cm^3)
Convection Oven	45°C	5	0.20±0.0409	0.23±0.0542	1.0155±0.0008
	55°C		0.21±0.0079	0.24±0.0062	1.0121±0.0004
	65°C		0.21±0.0079	0.24±0.0049	1.0209±0.0004
Microwave Oven	100W		0.21±0.0073	0.26±0.1533	1.0381±0.0006
	440W		0.20±0.0167	0.24±0.0121	1.0218±0.0008
	1000W		0.21±0.0127	0.24±0.0138	1.0268±0.0014
Air Fryer	120°C		0.18±0.0126	0.22±0.0136	1.0292±0.0012
	160°C		0.20±0.0068	0.23±0.0020	1.0042±0.0003
	200°C		0.21±0.0230	0.24±0.0362	1.0053±0.0007

Fitzpatrick et al., (2004) reported the smaller the size of the particle eliminates the void space, enhance the particles to arrange in close form resulting greater bulk density and smaller CI and HR value.

According to Table 14, the flowability of dried desiccated coconut are categorized in the range of free flow to fair. There are 7 sample of dried desiccated coconut ta varying drying treatment were qualified as free flow powder which were the sample obtained by convection oven drying at 45°C, 55°C, 65°C, microwave oven at 440W and 1000W and also air fryer drying at 160°C and 200°C as stated by Anandharamakrishnan (2017) where the moisture content affect the flowability of powder where higher moisture content decreased the flowability and contribute the powder unable to flow smoothly.

From the results obtained by air fryer drying, the CI and HR value obtained from the range of 12.87 to 16.98 and 1.15 to 1.20 respectively. This might be caused by the larger particle size developed at higher drying temperatures, which decreases bulk density and increases the calculated value of CI and HR, which revealed the flow properties of the sample.

However, for various drying treatments, the effect of temperature was incredibly important on the physicochemical characteristics of dried desiccated coconut. Smaller particles provided substantial bulk and tapped densities, and greater bulk densities enhanced the flowability. The convection oven drying at 55°C and 65°C, microwave oven at 100W, and air fryer drying at 200°C has a high bulk and tapped density, which is the most notable difference between the varying temperature or power in convection oven drying method, microwave oven drying method, and air fryer drying method. Nonetheless, the value of angle of repose obtained from varying drying treatment for all the dried desiccated coconut samples were in the range of 40°±0.5774 to 45°±0.5774 which is in the categories of fair to passable flow in Carr classification of the flowability according to the Angle of Repose from Carr RL,1965.

Table 14: Physical and flow properties of dried desiccated coconut according to angle of repose, Carr Index and Hausner ratio.

Drying Treatment	Temperature (°C) / Power (W)	Mass (g)	Angle of repose (°)	Carr Index	Hausner Ratio	Flowability
Convection Oven	45°C	5	40±1.0183	13.76	1.16	Good
	55°C		45±0.5092	11.67	1.13	Good
	65°C		45±0.5774	13.74	1.16	Good
Microwave Oven	100W		41±0.5774	18.10	1.22	Fair
	440W		40±0.5774	14.65	1.17	Good
	1000W		44±0.6939	15.49	1.18	Good
Air Fryer	120°C		42±0.3849	16.98	1.20	Fair
	160°C		44±0.6939	12.93	1.15	Good
	200°C		45±0.5774	12.87	1.15	Good

4.2.3 Colour

Table 15 presented the values obtained for colour measurement of desiccated coconut by different drying treatment. The whiteness, redness and yellowness of the sample were indicated by L*, a* and b* respectively. For the dried desiccated coconut, the most desire color were fair or light color. According to the result obtained, convection oven drying at 45°C, 55°C and 65°C and microwave oven drying at 100W, 440W and 1000W represented the L* value at the range of 90.75±0.32 to 91.59±0.25 contributed to highest value of L* which due to low drying temperature at different interval of drying time. However, it can be determined as lower temperature and equal drying rate that exposed to the samples reduce the chance of thermal degradation. Perussello, Amarante and

Mariani (2009) reported that the heat supplied during drying affects the chemical reaction between sugars and amine group in the sample, increasing its carbon content as well as the intensity of the pigment.

Air fryer drying at 100W, 440W and 1000W contributed to lower value of L* which were 89.60±0.22, 89.57±0.29 and 89.16±0.48 compared among convection oven drying and microwave oven drying. Sample dried in air fryer at 200°C has the lowest value of L*, a* and b* which contributed by highest drying temperature that cause browning of the desiccated coconut indicates that the sample undergone thermal degradation. Thus, the application of drying by using air fryer at 120°C, 160°C and 200°C is not appropriate to dry desiccated coconut. De Sousa et al., (2008) stated that smaller value of L* of powder products carries the pigment loss happened by oxidation or thermal effect. Nonetheless, a* value in air fryer drying at different temperature showed results of greatest value in the range of 0.26±0.85 to 0.50±0.06 presenting the redder color of dried desiccated coconut. However, the value of b* fall between 1.49±0.27 to 1.96±0.07 from all the dried desiccated coconut represent the higher the value of b* indicates the sample is more yellow in color. Taking all these into account, the temperature applied under air fryer drying treatment is not suitable to apply in desiccated coconut dehydration as the color degradation is too obvious compared to convection oven drying and microwave oven drying.

Table 15: Color values of dried desiccated coconut at vary drying treatment.

Drying Treatment	Temperature (°C) / Power (W)	L*	a*	b*
Convection Oven	45°C	90.85±0.45	0.17±0.11	1.89±0.18
	55°C	90.75±0.32	0.06±0.03	1.70±0.08
	65°C	91.28±0.29	0.09±0.12	1.81±0.27
Microwave Oven	100W	90.86±0.01	0.20±0.03	1.94±0.03
	440W	90.77±0.62	0.26±0.12	1.96±0.07
	1000W	91.59±0.25	0.07±0.04	1.69±0.17
Air Fryer	120°C	89.60±0.22	0.34±0.09	1.50±0.22
	160°C	89.57±0.29	0.50±0.06	1.91±0.26
	200°C	89.16±0.48	0.26±0.85	1.49±0.27

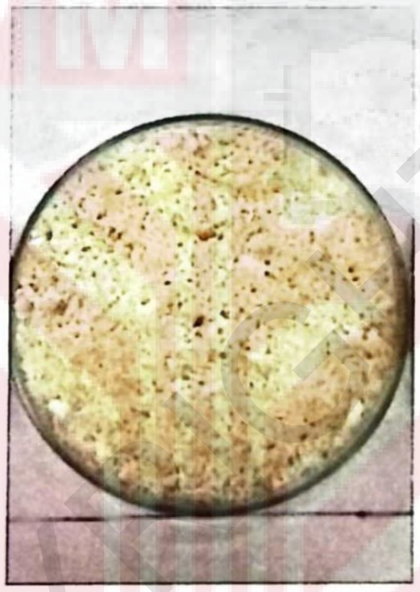

Figure 17: Top view of dried desiccated coconut by Convection oven (45°C).

Figure 18: Top view of dried desiccated coconut by Convection oven (55°C)

Figure 19: Top view of dried desiccated coconut by Convection oven (65°C)

Figure 20: Top view of dried desiccated coconut by Microwave oven (100W)

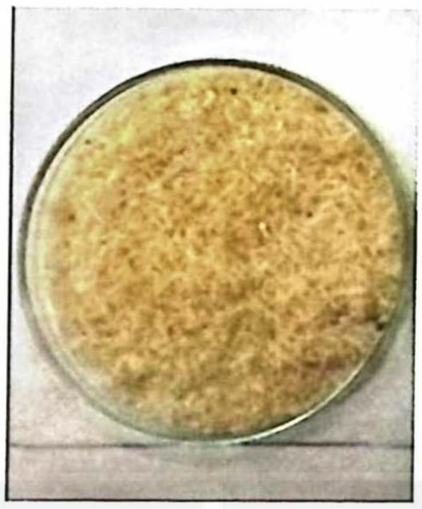

Figure 21: Top view of dried desiccated coconut by Microwave oven (440W)

Figure 22: Top view of dried desiccated coconut by Microwave oven (1000W)

Figure 23: Top view of dried desiccated coconut by Air Fryer (120°C)

Figure 24: Top view of dried desiccated coconut by Air Fryer (160°C)

Figure 25: Top view of dried desiccated coconut by Air Fryer (200°C

4.2.4 Surface Oil Content

The quantity of surface oil content can be referred to Section 2.3 in Table 2 as stated in the chemical and physical properties of a desiccated coconut (Codex Stan 177-1991). The oil contain that existed should not more than 60% mass per mass (m/m) which equivalent to 3g from a sample size of 5g that used to determine the surface oil content. The quantity of oil on the surface of dried desiccated coconut was shown in Table 16. From the result of the experiment, it was shown that the dried desiccated coconut by convection oven drying at 45°C, microwave oven drying at 100W and air fryer drying at 120°C showed the lesser surface oil content which were 0.0199 ±0.0008 g, 0.0197 ± 0 .0006g and 0.0147 ± 0.0007 g described by a long-time drying gave a significant effect on the quantity of oil on the surface of dried desiccated coconut and the major volatile compounds. Hence, 0.0218 ± 0.0007g, 0.0208 ± 0.0036 g and 0.0158 ± 0.0006 g of surface oil content were determined through an intermediate drying time and drying temperature or power at 55°C by convection oven drying, 440W by microwave oven drying and 160°C of air fryer drying respectively conduced a medium level of inter-particle collision which may not cause excessive in the excretion rate of the oil from inside of the desiccated coconut.(Niamnuy & Devahastin, 2005)

However, a higher temperature or power caused the surface oil content to increase. This is possibly because a higher temperature or power of drying gives an interior mass of oil greater ability to diffuse to the sample's outer surface. Comparing several samples that were dried using various drying equipment at low, medium, and high temperatures or powers, the sample which dried under convection oven at 65°C , microwave oven at 1000W and air fryer at 200°C had the highest quantity of surface oil which were 0.0229 ± 0.0007 g, 0.0255 ± 0.0013 g and 0.0192 ± 0.0004 g respectively due to greater collision that occurred imitated the squeezing action of desiccated coconut which led to an excretion of the oil from inside of the desiccated coconut.

Table 16: The quantity of oil on the surface of dried desiccated coconut.

Drying Equipment	Temperature (°C) / Power (W)	Surface Oil Content (g)
Convection oven	45°C	0.0199 ±0.0008
	55°C	0.0218 ±0.0007
	65°C	0.0229 ±0.0007
Microwave Oven	100W	0.0197 ±0.0006
	440W	0.0208 ±0.0036
	1000W	0.0255 ±0.0013
Air Fryer	120°C	0.0147 ±0.0007
	160°C	0.0158 ±0.0006
	200°C	0.0192 ±0.0004

4.3 Preliminary Cost Analysis for Varying Drying Treatment

This section will show the costs associated with three different drying treatment: drying in a convection oven, drying in a microwave, and drying in an air fryer through running expenses and equipment price in order to compare the costing for all drying treatment. The operating cost of each drying treatment is an important concern for industrial development of dried desiccated coconut. It is calculated according to the operating time in hour, power consumption by Watts and tariff according to low voltage industrial from Tenaga Nasional Berhad (RM 0.38 per unit used at first 200 units of electric usage).

In Table 17, the operating cost for convection oven is within RM 3.20 to RM 7.98 while for microwave oven drying and air fryer drying are RM 0.03 to RM 0.19 and RM 0.04 to RM 0.08 for three different temperature or power intensities respectively. The operating cost of convection oven drying is higher than microwave oven drying and air fryer drying because the drying time required to dry the same amount of desiccated coconut is longer. The power consumption of convection oven drying treatment is the highest with 2.8kW/h among the microwave oven drying, and air fryer drying which are 1kW/h and 1.425kW/h respectively.

According to Table 18, the equipment price for convection oven is much higher than microwave oven and air fryer. As a conclusion, the cost of convection oven drying is higher for both equipment price and operating cost in compare with microwave oven drying and air fryer drying.

Table 17: Operating cost for varying drying treatment.

Drying treatment	Operating time (h)	Power Consumption (Watts)	Operating cost (RM)
Convection oven drying (45°C)	7.50	2.8kW/h	7.98
Convection oven drying (55°C)	3.00		3.20
Convection oven drying (65°C)	5.00		5.32
Microwave oven drying (100W)	0.25	1kW/h	0.10
Microwave oven drying (440W)	0.5		0.19
Microwave oven drying (1000W)	0.08		0.03
Air fryer drying (120°C)	0.10	1.425kW/h	0.05
Air fryer drying (160°C)	0.15		0.08
Air fryer drying (200°C)	0.07		0.04

Table 18: Equipment cost for varying drying treatment.

Equipment	Price (RM)
Convection Oven	4,674.60
Microwave oven	938
Air fryer	446

CHAPTER 5
CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

Desiccated coconuts were dried by using varying drying treatment which were convection oven drying, microwave oven drying and air fryer drying. Three vary drying temperature of convection oven (45°C, 55°C and 65°C), microwave oven (100W, 440W and 1000W) and air fryer (120°C , 160°C and 200°C) were applied to produced dried desiccated coconut. The dried desiccated coconut was dried and gone through sieving to determine the particle size. The drying of desiccated coconut enhances the process of determination on the drying characteristics and physicochemical characteristics. Three different thin layer drying models (Page, Henderson & Pabis and Newton) were used to fit the experimental measurement from drying. Results obtained that Page model gave the best fit according to the highest R^2 value (0.9318 to 0.9885) for convection oven drying at all temperatures while for microwave drying the same model was established as the appropriate fit with larger R^2 value ranging from 0.5202 to 0.993 for all the power intensities and also fit for air fryer drying with the highest value of R^2 value in between 0.663 to 0.9931.

The second objective was focused on the physicochemical characteristics of dried desiccated coconut obtained. Statistical analysis was conducted to determine the particle size, compressibility, flowabilities, color and surface oil content. The result obtained showed convection drying method at temperature of 55°C produce the largest particle size of 17.55mm while microwave oven with 1000Wpower intensity and air fryer with 160°C produce the largest particle size as 17.68mm and 19.16mm respectively.

For the density analysis of the dried desiccated coconut, convection oven drying, microwave oven drying and air fryer drying at 65°C, 100W and 200°C have the highest value of bulk density, tapped density and true density (0.21±0.0079 g/cm^3, 0.24±0.0049 g/cm^3 and 1.0209±0.0004 g/cm^3; 0.21±0.0073 g/cm^3, 0.26±0.1533 g/cm^3 and 1.0381±0.0006 g/cm^3; 0.21±0.0230 g/cm^3, 0.24±0.0362 g/cm^3 and 1.0053±0.0007 g/cm^3) respectively.

However, at section 4.2.2, the flowability properties of the desiccated coconut was shown by the determination of densities, Carr Index and Hausner Ratio. The dried desiccated coconut samples presented the flowability ranging from fair to good. The color was measured for each of the samples from every drying treatment. The results revealed that the dried desiccated coconut sample become darker as the increases of temperature or power intensities.

Hence, the quantity of surface oil content for every dried desiccated coconut sample from varying drying treatment was obtained in order to justify the relationship in between temperatures or power intensities, drying time that influences the flowability of sample. Convection oven drying at 65°C, microwave oven drying at 1000W and air fryer drying at 200°C has highest yield of surface oil content which are 0.0229±0.0007g, 0.0255±0.0013g and 0.0192±0.0004g respectively.

In conclusion, desiccated coconut was dried effectively through microwave oven drying treatment which presented desire drying characteristics and physicochemical characteristics. This study recognized the parameter to deal with the issue of short shelf life of the desiccated coconut. The drying process under microwave oven drying treatment successfully achieve the final moisture content of 1.0506 g water / g dry solid and natural white to light creamy white in color which are favorable. Finally, the operating costing for convection oven drying is within RM 3.20 to RM 7.98, which is the highest among microwave oven drying in the range of RM 0.03 to RM 0.19 and air fryer drying in the range of RM 0.04 to RM 0.08. In terms of equipment costing, air fryer drying treatment is a better suit than convection oven drying treatment and microwave oven drying treatment as it was the cheapest and affordable price among this three equipment.

5.2 Recommendations for Future Research

The development of Malaysia's economy has a lot of potential for the coconut sector. A significant source of income for agricultural families is the upstream segment of the coconut industry. Implementing techniques to boost the growth of the nation's coconut industry will be able to minimize dependency on imported crops.

In this study, different drying treatment were study to compare the drying characteristics and the dried physicochemical characteristics. It is recommended to evaluate on how convection oven, microwave oven and air fryer affect the shelf life of dried desiccated coconut. The nutritional value of the dried desiccated coconut will be dependent to the temperature or power intensities and drying time that applied in this three-drying treatment. Therefore, future research can evaluate on how the drying treatment with different temperature, power levels and drying time affects the nutritional qualities of dried desiccated coconut. Determination of equal particle size and the color of desiccated coconut after drying considered as an important factor to consumer acceptance.

In another hand, high fat content also led to worse flow of powders (Perez and Flores, 1997). The fat content in the powder can disturb the flowability of powder. This can be due to the behavior of the powder can change when it is expose to the air and expose to the wall of hopper flow. The study of chemical composition of dried desiccated coconut should be considered in determine the flowability of powder because it also can be a major factor to determine the flowability of powder. Hence, increased fat content reduced powder flowability hence affect the life span of the dried product since unexpected lipid oxidation potentially trigger rancidity (Prachayawarakorn et al., 2008).

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APPENDICES A

EXPERIMENTAL DATA

Table 19: Final moisture content of different drying treatment.

Drying treatment	Temperature (°C) / Power (W)	Initial weight of sample (g)	Final weight of sample (g)	Final moisture content
Convection Oven	45°C	15.0143	6.9007	1.1758
	55°C	15.0507	7.0647	1.1304
	65°C	15.0483	7.1703	1.0987
Microwave Oven	100W	15.0145	7.3222	1.0506
	440W	15.0168	7.4608	1.0128
	1000W	15.0117	7.5415	0.9905
Air Fryer	120°C	15.0165	6.6844	1.2465
	160°C	15.0131	6.7473	1.2250
	200°C	15.0260	7.7375	0.9420

Table 20: Average mean particle size(mm) by using sieve shaker.

Heat Treatment	Temperature (°C) / Power (W)	Average Mean Particle Size (mm)
Convection oven	45°C	17.08
	55°C	17.55
	65°C	17.52
Microwave oven	100W	16.69
	440W	16.76
	1000W	17.68
Air Fryer	120°C	17.50
	160°C	19.16
	200°C	18.03

Table 21: Current rate for domestic tariff according to the usage.
(https://www.tnb.com.my/residential/pricing-tariffs)

Domestic Tariff	Current Rate (RM)
For the first 200kWh (1-200kWh) per month	0.218
For the next 100kWh (201-300 kWh) per month	0.334
For the next 300kWh (301-600 kWh) per month	0.516
The minimum monthly charge is RM3.00	

APPENDICES B

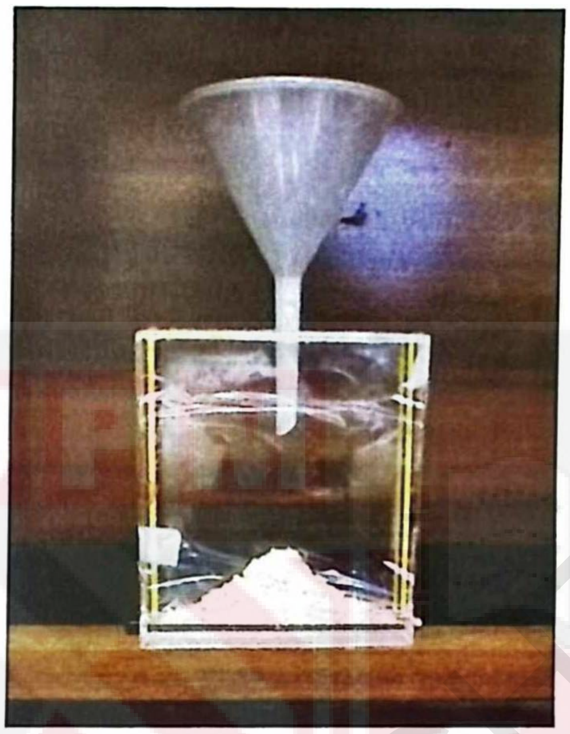

Figure 26: Angle of repose by using funnel and disc case.

Figure 27: Dried desiccated coconut was distributed evenly on the blotting paper in a drying tray for measuring the surface oil content.

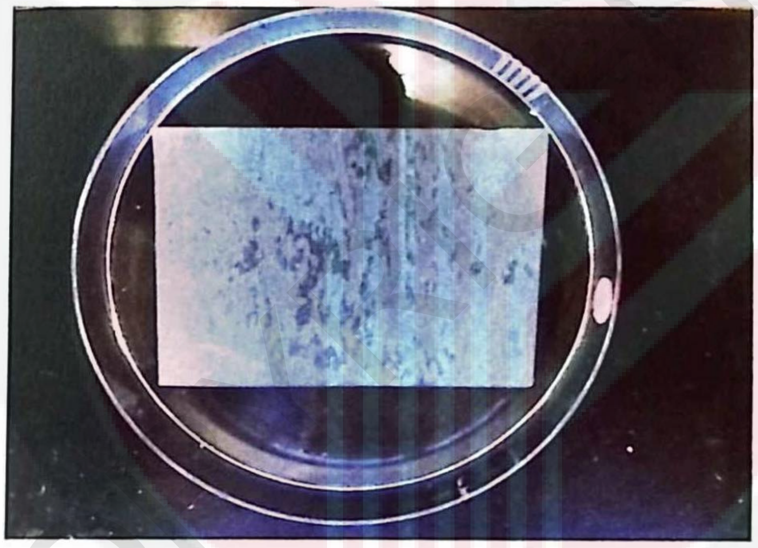

Figure 28: Blotting paper after absorption of surface oil content.